IMPROVEMENT OF POWER QUALITY OF CFL BULBS USING ACTIVE POWER FACTOR CORRECTION CIRCUIT

1.) Sudipta Modak……………. .(ID:10321036)

2.)Tapas Kumar Das …………..(ID:10221049)

3.)Mohammad Rafiqun Nabi …(ID:10321052)

Department of Electrical and Electronic Engineering

December – 2014

BRAC University, Dhaka, Bangladesh

DECLRATION

We hereby declare that, this thesis paper is based on the results found by our research work and other researchers are mentioned by reference. This thesis has not been previously submitted for any degree.

Signature of Supervisor: **Signature of Author:**

Date: **Date:**

ACKNOWLEDGEMENTS

We are very much grateful to our thesis advisor Amina Hasan Abedin (Assistance Professor) for guiding us in a right way throughout our thesis work. We were fortunate enough to be her student. She was very cooperative to us and supported us every single moments during the thesis paper and gave us the knowledge superbly we needed for our research paper. We worked hard together to bring something new and hopefully our work will be appreciated by our honorable advisor.

ABSTRACT

Power electronics is a means of controlling/processing in an appropriate way that is suitable for the load. Power conditioning is done to ensure higher efficiency and power density. Improved efficiency can reduce emission of heat/wasted power so that it can reduces environmental pollution.

Power electronic converters use semi-conductor switching devices that are operated in ON-OFF states. These converters have higher efficiency with the control of distorted input signals. The input signal distortion increases with the increased use of these converters. Various standards have been set to limit the level of distortion. One of the ways of measuring these distortions is THD. A signal having THD more than the specified range has some detrimental effect on the line to which it is connected. Lighting loads are one of the major powering applications. Approximately 19% to 20% of the power is used for this purpose. As a result high efficient lighting system is a major research area in power electronics. In this regard incandescent bulbs were replaced by discharge lights (those are operated in negative resistance region) long ago. A ballast circuit is included to limit the current flow in this circuit. Initially magnetic ballasts were used. However due to some disadvantages like flickering, size, high cost, low efficiency etc electronic ballast has taken place instead of magnetic ballast.

The focus of this thesis is in the electronic ballasts in discharge lamps and the total harmonic distortion produced due to the non-linear circuit situated in the lamps. The main objective is to minimize this distortion as far as possible. Various simulations have been done in order to measure the total harmonic distortion of ballast circuit situated on the CFL bulb. Moreover a power factor rectification circuit has been provided to improve the power factor and reduce the THD value of the ballast circuit.

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CHAPTER ONE

INTRODUCTION

One of the most challenging fields in Electrical engineering is the Power electronics sector. It is considered challenging because of the fact that Power electronics is regarded as one of the leading fields in the economic notion of low power consumption and also the minimal usage of electronic devices in industrial and household applications. The equipments used in Power electronics have by far been the most efficient in terms of size and cost as well as low power consumption. The usage of Power electronics equipments is vast in our daily activity and the world has been able to switch from huge and heavy machinery to light and small equipments because of its application. From a fan regulator to a UPS, from ballast to a television, everything uses transistors. These tiny electronic equipments have led to a revolution in electronics and have given rise to the study of Power Electronics to come forth and stand under the flood light. The research scope over this field is enormous and it gives rise to enormous possibilities of change in a variety of sectors.

Power electronics is the application of solid-state electronics for the control and conversion of power. It also refers to a subject of research in electronic and electrical engineering which deals with design, control, computation and integration of nonlinear, time varying energy processing electronic systems with fast dynamics. Power electronics is a means of controlling/processing in an appropriate way that is suitable for the load. Power conditioning is done to ensure higher efficiency and power density. Improved efficiency can reduce emission of heat/wasted power so that it can reduces environmental pollution. [1]

Power electronic converters use semi-conductor switching devices that are operated in ON-OFF stages. These converters have higher efficiency with the control of distorted input signals. The input signal distortion increases with the increased use of these converters. Various standards have been set to limit the level of distortion. One of the ways of measuring these distortions is

THD. A signal having THD more than the specified range has some detrimental effect on the line to which it is connected. Lighting loads are one of the major powering applications. A lot of the power is used for this purpose. As a result high efficient lighting system is a major research area in power electronics. In this regard incandescent bulbs were replaced by discharge lights long ago. A ballast circuit is included to limit the current flow in this circuit. Initially magnetic ballasts were used. However due to some disadvantages like flickering, size, high cost, low efficiency etc electronic ballast has taken place instead of magnetic ballast.

The focus of our thesis is in the electronic ballasts in discharge lamps and the total harmonic distortion produced due to the non-linear circuit situated in the lamps. The main objective was to research on the evolution of lamps and at the same time to point out the pros and thorns in each lamp circuitry. Furthermore we will be revealing our research on the evolution of ballasts used in modern bulbs compared to that of the ballast used a decade from now. We have also aimed to design simulations regarding the internal circuitry of ballasts situated at the base each CFL lamps and to find out the THD on the current supplied. The ballasts are small and light weight and consume low power but there is a significant power loss and due to the presence of non-linear circuitry in them they distort the shape of the input current. We aimed to minimize this distortion as far as possible. Various experiments have been done in order to measure the total harmonic distortion of different types of discharge lamps and luminous intensity of these lamps has been compared. Further work may be done on the ballast circuit to improve their THD factor and make them power friendly.

1.1 History of Power Electronics

Power electronics started with the development of the mercury arc rectifier. Invented by Peter Cooper Hewitt in 1902, it was used to convert alternating current (AC) into direct current (DC). From the 1920s on, research continued on applying thyratrons and grid-controlled mercury arc valves to power transmission. Uno Lamm developed a valve with grading electrodes making mercury valves usable for high voltage direct current transmission. In 1933 selenium rectifiers were invented. [2][3]

In 1947 the bipolar point-contact transistor was invented by Walter H. Brattain and John Bardeen under the direction of William Shockley at Bell Lab. In 1948 Shockley's invention of the bipolar junction transistor improved the stability and performance of transistors, and reduced costs. By the 1950s, semiconductor power diodes became available and started replacing vacuum tubes. In 1956 the silicon controlled rectifier (SCR) was introduced by General Electric, greatly increasing the range of power electronics applications. [4]

In the 1960s the switching speed of bipolar junction transistor allowed for high frequency DC/DC converters. In 1976 power MOSFET became commercially available. In 1982 the Insulated Gate Bipolar Transistor (IGBT) was introduced. [4]

1.2 The Science of Lights and History of Lamps

The first light sources created by humans were produced thousands of years ago in the Neolithic period by burning tree branches and dried grass to provide light in the nighttime darkness. Thus began the age of combustible light sources. Eventually, people learned to fashion oil lamps by placing animal and vegetable oils in containers made of stone, clay and shell and then dipping wicks into the oil. While it remains unclear where and when human beings first made the transition from small lamp fires to oil lamps, the oldest known lamp today is thought to be a sandstone lamp unearthed from the La Mouthe caves in France. Over the centuries, oil lamps passed through many stages of evolution, including lamps shaped like teapots, lamps made of stone, ceramics and metal, and they came to hold an important place in many homes. However, the invention of the kerosene lamp by an American B. Syrian resulted in the gradual disappearance of the oil lamp. Finally, the discovery of electrical energy brought the introduction of electric lamps and light bulbs and the age of electrical lighting supplanted the age of combustion lighting. [5]

The age of electric light dawned in 1808 with an English-man Sir H. Davy's invention of the first electric light, the arc lamp. However, because Sir H.Davy's arc lamp was very luminous and dirtied the air through the emission of carbon steam, it was only useful for lighting roadways. At around the same time, another Englishman, Warren de la Rue created an incandescent light bulb using a platinum coil. Unfortunately this light bulb was too expensive and short-lived to be of practical use there was one scientist, however, who provided a ray of hope for the difficult beginning of the age of electrical light. The name of this scientist was W. R. Glove. In 1840 Glove invented an incandescent light bulb using a platinum coil and achieved the practical use of electric light. Mr. Glove's work toward perfecting electric light for practical use was followed by many bright developments, such as Sir J. W. Swan's success in 1860 in producing a carbon light bulb by carbonizing paper and processing cotton fiber with sulfuric acid. Finally in 1879, Thomas A. Edison invented the carbon light bulb which is the basis of modern incandescent lamps. [5]

The innovative and creative Edison, whose motto was "Genius is 99% perspiration and 1 % inspiration", and who said "I continue to invent in order to raise the money to invent", invented the incandescent light bulb during the most productive period in his life, between the years 1876 and 1881. Immersed in research into the development of incandescent light bulbs from 1878, on October 21st 1879 Edison succeeded in demonstrating a light bulb which used an improved mercury exhaust pump and carbon filament to shine for more than 40 hours. Upon discovering that bamboo was an excellent filament material, Edison acquired samples of bamboo from around the world. Edison found that Hachiman bamboo from the Kyoto area of Japan was best suited to his purposes and continued to use this bamboo for ten years thereafter. In order to popularize electric lighting, Edison also designed a host of devices related to electric light bulbs, wiring and the generation and transmission of electricity, such as sockets, switches, safety fuses, watt-hour meters and switchboards. [5]

On the other hand, while discharge lamps began with arc lamps and the German inventor Geissler devised the Geissler tube in 1859, these lamps were overshadowed by the remarkable progress being made with incandescent lamps and went largely unnoticed. However, in 1893 the Moore lamp was invented and the development of discharge lamps began to take a more promising course. Neon lights where invented in 1914 and finally in 1938 the American inventor Inman invented the fluorescent discharge lamp. [5]

Electric lamps and light bulbs underwent various enhancements as the result of a variety of successes and failures and have progressed in tandem with improvements in human lifestyles.

Today, lighting technology has advanced to the point that electric lights have become an essential part of our daily lives. Every day incandescent, fluorescent, halogen and HID lamps provide light where we live, study, work and play. [5]

1.3 Types of Lamps Included in the Thesis

There are a number of lamps that have been developed since the discovery of electricity. Since then several lamps have been developed and used globally. Through this thesis we have come across three types of lamps which are:

1. Incandescent Lamps
2. Discharge Lamps
3. LED Lamps

1.3.1 Incandescent Lamps

An incandescent lamp or incandescent light globe is an electric light which produces light with a filament wire heated to a high temperature by an electric current passing through it, until it glows. The hot filament is protected from oxidation with inert gas or evacuated. In a halogen lamp, filament evaporation is prevented by a chemical process that redeposit metal vapor onto the filament, extending its life. The light bulb is supplied with electrical current by feed-through terminals or wires embedded in the glass. Most bulbs are used in a socket which provides mechanical support and electrical connections. [6]

The incandescent lamp was the second form of electric light to be developed for commercial use after the carbon arc lamp. It is the second most used lamp in the world today behind fluorescent lamps. Incandescent bulbs work by sending electric current through a resistive material. For making a good filament we have to use such types of materials which have high melting point. Now question might comes "Why does the material emit light when we pass electric current through it?" The fact is when we pass current through a filament material, the resistance creates heat. By this time atoms in the material absorb energy. That's why electrons around the atoms get excited and temporarily reach an orbital which is further from the nucleus. Incandescent is basically thermal radiation. Heat is constantly emitted from objects around us, we just can't see it. When heat gets intense enough it reaches wavelengths that can see. [7]

Advantages of Incandescent Lamps

An incandescent bulb will emit its rated brightness immediately than a fluorescent bulb because fluorescent bulb takes more time to emit any light. Incandescent light will also produce a "warmer" colored light. On the other hand, fluorescent lights tend to produce much colder temperature light. That's why incandescent light can seem softer, less harsh. The another advantage of incandescent light is it doesn't flicker but fluorescent lights all flicker at the speed of the alternating current supply, 50 of 60 times a second. Lastly incandescent lights are not putting the environment at risk because it doesn't contain any quantity of toxic materials (like mercury, toxic alloys or semiconductor). But fluorescent bulbs contain some amount of mercury in them. Of course, fluorescent use more energy and so it damages the environment in that way. Incandescent light is great to use for small area lighting as well. The most important thing about incandescent light is that, it's very cheap to produce and no AC current distortion happens here. [6][7]

Disadvantages of Incandescent Lamps

When efficiency is the main focus in a lighting design, incandescent lighting is a poor choice. Compared with the other major light sources incandescent is the least efficient. When a lighting design calls for energy efficiency, fluorescent or high intensity discharge lighting makes more sense. Approximately 90% of the energy that is consumed in an incandescent lamp is release in the form of heat while only 10% is converted to visible light. The added heat load from an incandescent lighting system requires more cooling capacity and thus higher energy costs during the cooling season. Incandescent lamps also operate at shorter lives than most other lighting sources. Incandescent bulbs are not useful for lighting large areas and this is one of the most important disadvantages. Incandescent lamp takes many to light a large area where as only one HID lamp can light a large open area. [6] [7]

1.3.2 Discharge Lamps

1.3.2.1 Basic Operation

The basic concept of discharge lamps is the transformation of electric energy into electromagnetic radiation inside a discharge tube. The discharge tube is made up of a transparent material with scaled electrodes at both ends of the tube. The tube is filled with an inert gas and a metal vapor. The electrodes generate free electrons which are accelerated by the electric field existing in the tube. Now these accelerated electrons collide with the inert gas atoms and undergo both elastic and inelastic collisions [1]. There are three basic processes that take place inside the tube:

1.) Heat generation: In this process heat is emitted to set an optimum temperature for further operations. When the kinetic energy of the electron is low elastic collisions take place and heat is generated which increases the temperature of the gas there by setting in an optimum operating temperature [1].
2.) Gas atom excitation: Discharge tubes contain a phosphorous coating on the inside of the tube. An electron having very high kinetic energy collides with a gas atom sending one of its electrons to a higher orbit. This situation is not stable and therefore the electron returns to its original level and emits the absorbed energy in the form of electromagnetic radiation which is used to generate visible light [1].
3.) Gas atom ionization: in this process an electron from the electrode is powered-up by accelerating it with very high kinetic energy. When this electron hits an atom it knocks out an electron from the atom making it ionized and also obtains a free electron. This

process is required for current to flow through the lamp as electrons and ions can carry charge [1].

Focusing on discharge lamps, the complete stabilization process consists of two main phases:

1.) Breakdown phase: Most of the gases are very good insulators and an electric discharge is only possible if an adequate concentration of charged particles is present. Generally a high voltage is used to provide electricity carriers and to initiate the discharge. The minimum voltage applied to initiate the discharge is called starting voltage. “Paschencurves” is a function which determines the starting voltage as a function of the product of gas pressure multiplied by electrode distance. The using of auxiliary inert gases presenting a very low starting voltages, which are called penning voltage [1].
2.) Warm-up phase: When the lamp is ignited, the collisions between electrons and atoms generate heat and discharge temperature increases until normal operating conditions are reached. The metal atoms are evaporated in the existing discharge tube by this heat and emitted electromagnetic radiation. From the electrical point of view, the discharge warm-up phase shows initially low discharge voltage and high discharge current. The discharge voltage increases how long the metal atoms are evaporated. At last the equilibrium state is reached at steady- state operation with the normal values of voltage and current [1].

1.3.2.2 Types of Discharge Lamps

Low pressure discharge lamp: It operates at pressure around 1 Pa and features low current density and low power per unit of discharge length. It also presents large discharge volume with a low power rating. Low pressure mercury lamps (also known as fluorescent lamp), low pressure sodium lamps are some examples of low pressure discharge lamp. [1]

High pressure discharge lamp: It operates when the operating pressure is more than 10^5 Pa. It also presents high current density in discharge and high power per discharge length ratio. It shows much smaller discharge volume. High pressure sodium lamps, high pressure mercury lamps metal halide lamps are some examples of high pressure discharge lamps. [1]

CCT (Correlated Color Temperature) and CRI (Color Rendering Index) are very important concepts to characterize the light produced by a discharge lamp.

1.3.2.3 Fluorescent Lamp

A fluorescent is a low pressure discharge lamp consisting of a tube coated on the inside with a fluorescent material; mercury vapor in the tube emits ultraviolet radiation which converted to visible radiation by the fluorescent material. when current flows in the gas excites mercury vapor which produces short-wave ultraviolet light which causes a phosphor coating on the inside of the bulb to glow. A fluorescent lamp converts electrical energy into useful light much more efficiently than incandescent lamp. Fluorescent lamps are used to both outdoor and indoor, backlight for LCD displays, decorative lighting and signs, both high bay and small area general lighting. Not used for lighting from afar due to diffuse nature of the light. [8]

The tube of the fluorescent lamp contains a low pressure mercury vapor as well as the inert gases like argon, xenon, neon, krypton etc. The inner surface of the tube is coated with fluorescent having an atmospheric pressure of 0.3%. The lamp's electrodes are typically made of coiled tungsten and usually referred to as cathodes because of their main function of emitting electrons. We know fluorescent lamp converts electrical energy into radiant energy and it relies on an inelastic scattering of electrons. When an incident electron collides with an atom in the gas it transfers energy to the atom's outer electron, causing that electron to temporarily jump up to a higher energy level, as result electron have to lose its kinetic energy and that is why is the process is called inelastic scattering. Electrons jump to higher energy level but they return back to lower energy level because higher energy levels are not stable as the lower energy level, as a result atoms emit an ultraviolet photon, Most of the photons that are released from the mercury atoms have wavelengths in the ultraviolet region of the spectrum, at wavelengths of 253.7 and 185 nanometers (nm). These are not visible to the human eye, so they must be converted into visible light. This is done by making use of fluorescence. Ultraviolet photons are absorbed by electrons in the atoms of the lamp's interior fluorescent coating, causing a similar energy jump, then drop, with emission of a further photon. The photon that is emitted from this second interaction has a lower energy than the one that caused it and these emitted photons are at wavelengths visible to the human eye. [1] [8]

Advantages of Fluorescent Lamps

Fluorescent lamp is energy efficient. It is so far the best light for interior lighting. It has a low production cost. The tubes have long lives and are durable. It has a good selection of desired color temperature. It provides diffused light which is good for general, even lighting and reducing harsh shadows. [9]

Disadvantages of Fluorescent Lamps

Different physical problems for human like eye strain, headaches, migraines etc could be cause by the flicker of the high frequency. Flicker of common fluorescent light looks poor on video, and creates an ugly greenish or yellow hue on camera. Diffused Light is not good when one needs a focused beam such as in a headlight or flashlight. Poorly designed ballasts can create radio interference that disturbs other electronics. Poorly designed ballasts can create fires when they overheat. There is a small amount of mercury in the tubes. There is always an irritating flicker at the end of the life cycle. [8]

One of the most important things about fluorescent lamps is negative differential resistance devices so as more current flows through them, the electrical resistance of the fluorescent lamp drops, allowing for even more current to flow. Lamps are basically connected to a constant-voltage power supply as a result uncontrolled current flow will destroy the lamps. So the term Ballast comes here to prevent these lamps from uncontrolled current flow and the main purpose of the ballast is limiting the current flow. [8] [9]

1.3.2.6 Compact Fluorescent Lamp

A compact fluorescent lamp (CFL), also called compact fluorescent light, energy-saving light, and compact fluorescent tube, is a fluorescent lamp designed to replace an incandescent lamp;

some types fit into light fixtures formerly used for incandescent lamps. The lamps use a tube which is curved or folded to fit into the space of an incandescent bulb, and compact electronic ballast in the base of the lamp. Compared to general-service incandescent lamps giving the same amount of visible light, CFLs use one-fifth to one-third the electric power, and last eight to fifteen times longer. A CFL has a higher purchase price than an incandescent lamp, but can save over five times its purchase price in electricity costs over the lamps lifetime. A CFL bulb is cost effective in usage as it uses low amount of power and at the same time it is over than 90% efficient. However the problem with CFL bulbs is the internal circuitry due to the usage of ballast. These bulbs have to be supplied at high frequency with cannot be obtained from the line as the line frequency is 50Hz or 60Hz. Therefore ballast has to be used to enhance the frequency and due to this the bulb distorts the input current wave-shape and gives rise to harmonics which drains power in the form of reactive power. One other problem is the usage of mercury in these bulbs. Mercury is poisonous to all living being and once the blub gets damaged mercury could spill out and harm people. Thus a new type of bulb emerged known as LED lamps. The advantage over CFLs of LEDs is that there is little or no distortion and also no mercury usage so it is environmental friendly. In our thesis we have no researched much on LED. Our work is based on the internal circuitry of CFL as due to the huge cost not everyone can afford LED lights.

1.3.3 LED Lamps

LED means light emitting diode which is a two-lead semiconductor source. It is a basic pn-junction diode, which emits light when activated. When a fitting voltage is applied to the leads, electrons are able to recombine with electron holes within the device, releasing energy in the form of photons. This effect is called electroluminescence, and the color of the light is determined by the energy band gap of the semiconductor. LED lamps have big lifespans and high electrical efficiency that is several times better than incandescent lamp, and significantly better than most fluorescent lamp, with some chips able to emit more than 100 lumens per watt. Like incandescent lamps and unlike most fluorescent lamps LED can be fully ignited without any extra time spent for it to be warm. The life of fluorescent lights can be reduced by high switching on and off. The cost of LED is higher than other types of bulbs. [10]

The LED lamp market is projected to grow by more than twelve-fold over the next decade. LEDs use less energy than do other forms of lighting, including compact fluorescent (CFL) and incandescent bulbs. A typical LED bulb can produce around 83 lumens per watt compared with 67 for a comparable CFL bulb and 16 for an incandescent. LEDs produce light by passing electric current through a semiconductor, whereas incandescent bulbs pass current through a wire filament until it glows from the heat. The heat energy which is wasted is mainly the reason for incandescent bulbs to be less efficient. [10]

A light-emitting diode consists of a number of layered semiconductor materials. In the LED, electricity is directly converted into light particles, photons, leading to efficiency gains compared to other light sources where most of the electricity is converted to heat and only a small amount into light. In incandescent bulbs, as well as in halogen lamps, electric current is used to heat a wire filament, making it glow.

Advantages of LED Lamps

LED bulbs last up to 10 times as long as compact fluorescents and also far longer than any typical incandescent. Since LEDs do not have a filament, they are not damaged under circumstances when a regular incandescent bulb would be broken. Because they are solid, LED bulbs hold up well to jarring and bumping. These bulbs do not cause heat build-up. Common incandescent bulbs get hot and contribute to heat build-up in a room. LEDs prevent this heat build-up, thereby helping to reduce air conditioning costs in the home. No mercury is used in the manufacturing of LEDs. LED light bulbs use only 2-17 watts of electricity. LED bulbs used in fixtures inside the home save electricity, remain cool and save money on replacement costs since LED bulbs last so long. Small LED flashlight bulbs will extend battery life 10 to 15 times longer than with incandescent bulbs. Although LEDs are initially expensive, the cost is recouped over time and in battery savings. LED bulb use was first adopted commercially, where maintenance and replacement costs are expensive. However the cost of new LED bulbs has gone down considerably in the last few years and is continuing to go down. Today, there are many new LED light bulbs for use in the home, and the cost is becoming less of an issue. [11]

Disadvantages of LED Lamps

LED lamp is only now emerging as a practical option, so the cost is currently higher than other solutions. In many applications, LEDs are expensive compared with other light sources, when measured by metrics such as "dollars-per-lumen". Although LED manufacturers continue to work towards reducing their production costs while at the same time increasing the light output of their devices it is taking time to grab the market. LED performance largely depends on the ambient temperature of the operating environment. Over-driving the LED in high ambient temperatures may result in overheating of the LED package, eventually leading to device failure. Adequate heat-sinking is required to maintain long life. This is especially important when considering automotive, medical, and military applications where the device must operate over a large range of temperatures, and is required to have a low failure rate. There is a concern that blue LEDs and cool-white LEDs are now capable of exceeding safe limits of the blue-light hazard as defined in eye safety specifications. Most cool-white LEDs have spectra that differ significantly from a black body radiator like the sun or an incandescent light. The spike at 460 nm and dip at 500 nm can cause the color of objects to be perceived differently under cool-white LED illumination than sunlight or incandescent sources, due to meta-merism, red surfaces being rendered particularly badly by typical phosphor based cool-white LEDs. However, the color rendering properties of common fluorescent lamps are often inferior to what is now available in state-of-art white LEDs. LEDs must be supplied with the voltage above the threshold and a current below the rating. This can involve series resistors or current-regulated power supplies. Blue pollution, because cool-white LEDs emit proportionally more blue light than conventional outdoor light sources such as high-pressure sodium lamps, the strong wavelength dependence of Rayleigh scattering means that cool-white LEDs can cause more light pollution than other light sources. The International Dark-Sky Association discourages the use of white light sources with correlated color temperature above 3,000 K. [11]

1.4 Objective of the Thesis

Now-a-days the world has changed its lighting materials all around from incandescent lamps then to fluorescent lamps to compact fluorescent lamps. Due to the high power consumption in incandescent lamps and very low efficiency provided by them fluorescent bulbs were developed. These bulbs have a higher luminous efficiency and also consume less power compared to incandescent lamps. The efficiency is also greater compared to only 10% in incandescent lamps. The main objective of this thesis is to analyze the drawbacks of CFL and the factors affecting the overall performance and efficiency of the CFL. One main issue of the ballast used in the CFL has a non-linear circuit which gives rise to the term THD. Due to this distortion the overall power consumption of the bulb is actually higher than inscribed on the pack. This also leads to the distorted shape of the input voltage sinusoidal wave-shape. The purpose was to develop a circuit where the THD is low compared to that of the actual circuit. It is seen that CFL bulbs are found to be of different power factor ratings. We have used two bulbs of power factor 0.65 and 0.9 and we have found out that the lamps might have an efficiency of more than 90% but the distortion caused by the bulb of power factor 0.65 is quite greater than the distortion caused by the bulb with 0.9 power factor. The cost of a high power factor lamp is around double compared to that of the low. Taking this into account we have developed a circuit where we can increase the power factor. This circuit is called a power factor correction circuit and we have induced the circuit in the internal circuit of ballast. Simulations have been done to ensure the rectification of power factor of a CFL and the results are recorded and displayed in the later chapters.

1.5 Thesis Organization

The thesis started with an introduction in explaining and introducing the light bulbs we have used in our thesis along with the advantages and disadvantages of each type to lamp we used. The Light bulbs used were Incandescent bulbs, Fluorescent bulbs and Compact Fluorescent bulbs. We have also considered the usage of LED lamps which are now used in many parts of the world but are quite expensive and yet very efficient with a greater life expectancy.

We then moved to the internal circuitry of the CFL and focused on ballast used in the lamp. We have also shed light on the usage of different types of ballast used through time. Magnetic ballast had been used for a long time to supply fluorescent lamps but now the world is switching to electronic ballast for better efficiency. The mechanism of both type of ballast is explained in the chapter named Overview on Different types of Ballasts. We have provided circuit diagrams and mentioned the basic operations of each type of ballast. The reason why the use of electromagnetic ballast reduced and the increase in the usage of electronic ballast came to be is also explained in chapter two. Moreover the transition of the change is also mentioned along with the advantages and disadvantages of both types of ballast. We have also compared the two types of ballast and provided statistics by researching.

The next chapter consists of the type of ballast we used for our thesis. We have used non-resonant ballast because our work was on CFL which consumed low amount of power. We have provided power simulation schematics and graphs in our paper in chapter three where we have explained the main work of our thesis. The chapter also consists of our assumptions and experiments which we have used and calculated our values from. We have also provided an entire schematic diagram of the design we used to reach our goal.

In the final chapter of this thesis we have given an end of the thesis. We have briefly explained our findings and contribution. We have also provided what further research can be done to improve the overall rectifier and inverter circuit we have used in the ballast.

Using our research and simulations we have attained the work procedure of ballasts and lamps and also made it more power efficient using a power factor correction circuit.

CHAPTER TWO

OVERVIEW ON DIFFERENT TYPES OF BALLASTS

2.1 Electromagnetic Ballast

Electromagnetic ballasts employ core and coil transformers to operate lamps. They are intended to control the electric current and the flow at an appropriate level for the bulbs. Magnetic ballasts are “core-and-coil” electromagnetic ballasts. They contain a magnetic core of several laminated steel plates wrapped with copper windings. Magnetic ballasts usually have greater power losses than electronic ballasts. Some magnetic ballast employs an igniter which comes together with metal halide or sodium lamps. Although this type is the simplest, it is characterized by higher robustness. The magnetic ballast is capable of withstanding exposure to fluctuations and transients within an electric system, along with temperature extremes. Typically, the magnetic type of ballasts is used with fluorescent and neon lamps. Since magnetic ballasts are not as sophisticated as electronic ballasts and can be problematic, they are being replaced by the electronic versions. Magnetic ballasts are found in the light socket in between the plug for the light bulb and the power chord. [1] [12]

Flourescent lamps exibit a negative resistance characteristic. This requires that an inductive ballast (also called choke) be used in series for stable operation. Since the lamp impedance is essentially resistive. The three voltages in the circuit that is shown in the below figure are related as:

$$V_{Ballast}^2 + V_{Lamp}^2 = V_s^2$$

The lamp and the ballast characteristics are plotted in below figure in terms of V^2 and I. the intersection of the two characteristics provides a stable operating point.

In magnetic ballasts, current flows through coils of copper wire before moving on to the light bulb. Most of the current gets caught in the magnetic field it generates, with only small increments moving on to the light bulb. The current that is passed on depends on the thickness and the length of the copper coil. This inconsistent flow of the current is what causes the lights of the lamp to flicker and also creates the buzzing sound.

The low frequency electronic ballast is a variation of the magnetic one, incorporating some electronic components. Electromagnetic ballast is an essential component in traditional discharge lamps and tubes. In order to properly these lamps, an initial high current is needed which needs to be limited afterwards to prevent the lamp from blowing out or melting down. This function is performed by ballast. Electro-magnetic ballasts were one of the first components that could provide sufficient starting current to fluorescent lights. Although they are being replaced by much lighter and efficient, electronic ballasts, electro-magnetic ballasts are still in trend. [12][13]

We know current forms an arc through the lamp; it ionizes a higher percent of gas molecules. When a higher percentage of molecules become ionized, the resistance of the gas becomes significantly less. We know that no resistance means it acts like a short circuit. So without the ballast current would rise so high that the lamp would melt and destroy itself. So it is necessary to control the current by using ballast. The transformer in ballast is a coil of wire called an inductor. It creates a magnetic field. The more current we put through, the bigger the magnetic field, however the larger magnetic field opposes change in current flow. This slows the current growth. We know the current flows in one direction for only 1/60th or 1/50th of a second, then drops to zero before flowing in the opposite direction. Therefore the transformer only has to slow current flow for a moment. [1]

2.1.1 Basic Operation of Electromagnetic Ballast

The magnetic ballast literally "chokes" off the current at a set point. It does this by taking advantage of some basic physics. The electric power in our houses is either 50 or 60 cycle alternating current. In a "cycle," the flow of electricity goes from no flow at all, up to a set voltage, then back to zero, then goes the other way, from zero up to the set voltage, then back to zero. The current in that arc in the bulb does the same thing. It goes from zero to maximum, back to zero, then the other way, then back to zero. The ultraviolet light from the arc also goes from zero to maximum, back to zero, up to maximum, then back to zero. The glow from the phosphor powder coating the inside of the bulb does the same thing, except the powder never completely stops glowing. In a magnetic ballast, the rapid changes in current direction (the "cycles per second," or "Hertz") makes equally rapid changes in the magnetic field generated by the coil of wire in the ballast. The magnetic field reverses 120 times a second. (Each "cycle" or "Hertz" goes from zero up, then back to zero, then the other way, then back to zero.) The corresponding current in the arc in the bulb is doing the same thing.

The "fighting" magnetic fields and currents in the magnetic ballast "fight" much stronger as the amount of current flowing through the ballast increases. This "fighting" impedes, or chokes, the current flow. Ballast is designed by the Engineers so that it will let just exactly the right amount of current through to light that particular fluorescent bulb, but not let too much current through. It gets hot from the effects of the "fight." That heat is totally wasted electricity.

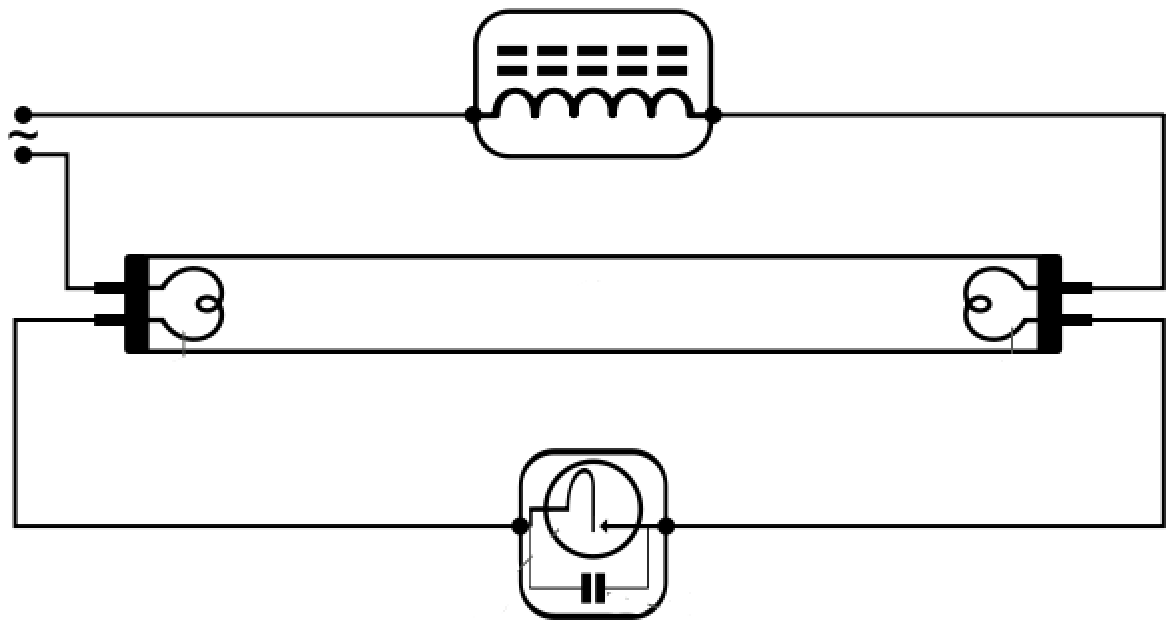

Figure 2.1: Circuit Diagram of Electromagnetic Ballast

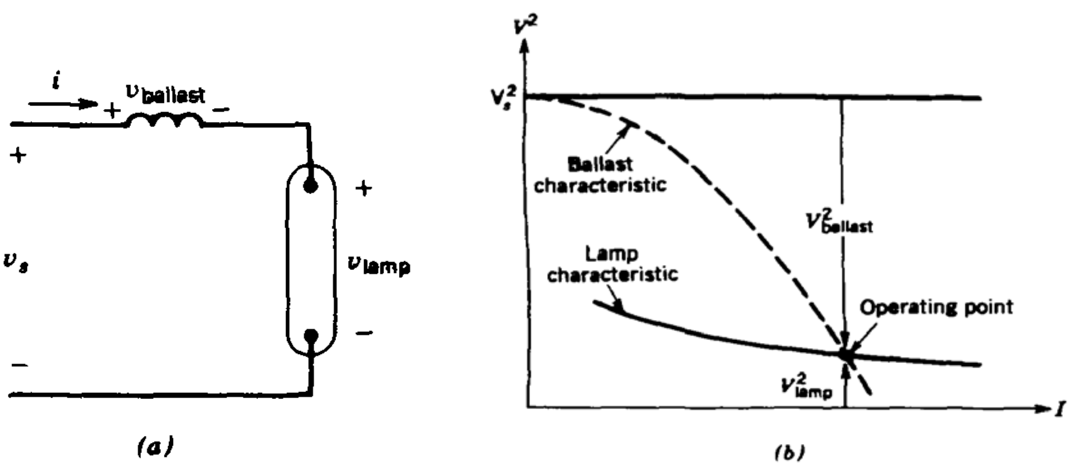

Figure 2.2: flourescent lamp with an inductive ballast.

A circuit schematic for the conventional 50-Hz rapid-start has shown in figure (a) which is consists of two lamps in series. The lamp cathodes are continuously heated by the cathode heater windings A,B and C. For explaining the basic operation we have redrawn the circuit in figure (b) without the heating windings. The autotransformer(primary in series with secondary) makes the input voltage boosted and the leakage inductance needed for a stable operation. Compared to an unignited lamp the starting capacitor has a low impedence and high impedence compared to an ignited lamp.. Then the series combination of lamps A and B in series with a power factor correction capacitor , which is used to correct an otherwise poor power factor of operation. [1]

At figure (b) we have an input voltage which is 50 Hz line frequency. Two lamps A and B are in series and a starting capacitor is in parallel with lamp B. when input voltage starts going, first it goes through the starting capacitor and the capacitor get charged and therefore at start-up, the starting capacitor provides a shunt across lamp B So it works like shorted and that is why maximum voltage goes through lamp A and that makes lamp A ignited. When lamp A got ignited the reactance of this lamp also decreases by time. After sometimes when the reactance of lamp A becomes very low it helps lamp B for being ignited. We also use another capacitor called power factor correction capacitor which is connected with the auto transformer. In this ballast circuit we use two capacitors and one auto transformer. So the size of this ballast becomes larger and weight becomes heavier. [1]

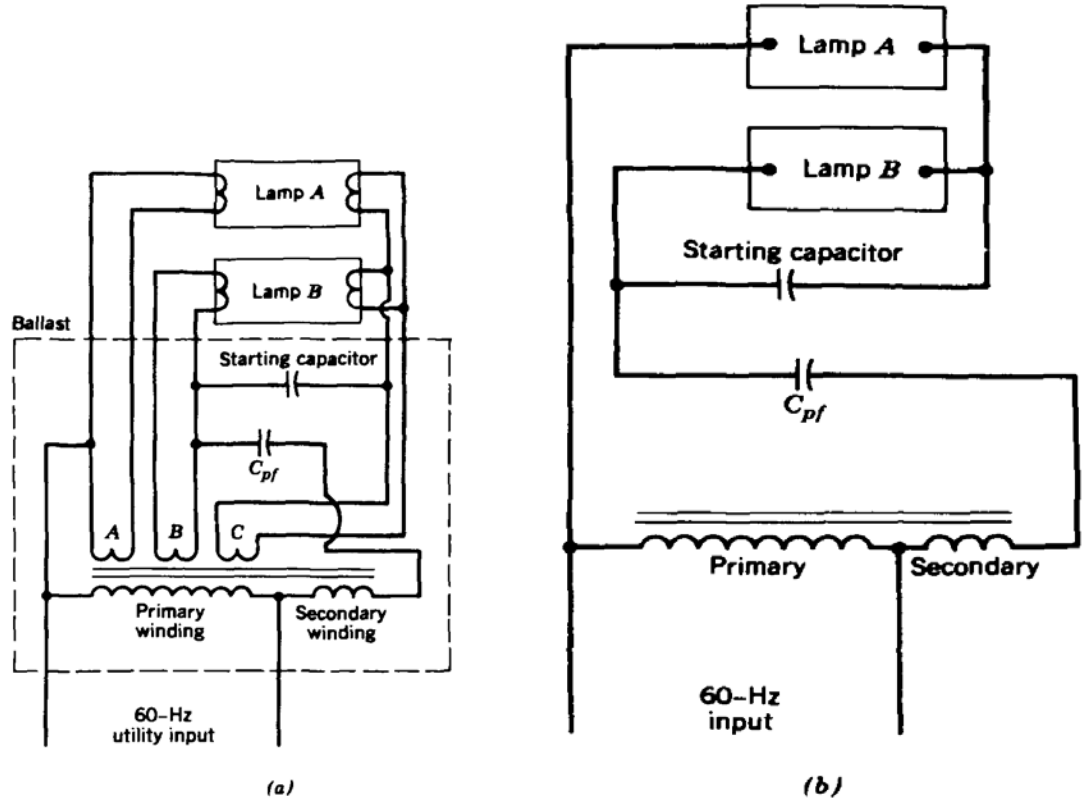

Figure 2.3: Typical model of conventional 50-Hz rapid-start fluorescent lamp

(a): circuit schematic, (b): simplified schematic.

Advantage

Magnetic ballast is cheaper. Magnetic ballasts are relatively reliable when designed properly and ballast construction is simple as well.

Disadvantage

In magnetic ballasts, current flows through coils of copper wire before moving on to the light bulb. Most of the current gets caught in the magnetic field it generates, with only small increments moving on to the light bulb. The current that is passed on depends on the thickness and the length of the copper coil. This inconsistent flow of the current is what causes the lights of the lamp to flicker and also creates the buzzing sound. Efficiency is low, especially for those ballasts featuring good lamp power regulation against line voltage variation. Low reliability and low input power and also have the difficulty to control the lamp luminous flux. In industrial environment it's also harmful for any moment so that electric ballast becomes the first choice instead of it.

2.1.4 Electronic Ballast over Magnetic Ballast

Electronic ballast and magnetic ballast are the two main types of ballasts used in certain light sources. There is a big difference in how ballast works and how it affects the lighting in your rooms. Light ballasts are small devices that are very important to the function of fluorescent lamps. Also sometimes referred to as the control gear, light ballasts have a negative electrical resistance, thereby limiting the current passing through the lamps. The flicker or the buzzing sound is due to the type of light ballast used. In addition to not flickering and being quieter than magnetic ballasts, electronic ballasts are preferred because it has many other advantages. They are smaller in size and weigh less. They are also great for the environment and your bank account because they are energy efficient and therefore lower your monthly energy bill. [15][13][14]

Another advantage is that electronic ballasts can be used in lamps that are in parallel and series mode. If one of the lamps goes out, this will not affect the other lamps even though all the lamps are using the same ballast. Also, if one wants to replace your magnetic ballast with electronic ballast, this is cheap and relatively easy to do. [13][14]

Due to the problems of magnetic ballast (high power uses,low efficiency,low realiability, difficult to control luminous flux, greater size and weight) the world switched from magnetic ballast to electronic ballast as the electronic ballast is chipper to produce, lighter in weight and smaller in size and most importantly it's portability. However the main reason for switching from magnetic to electronic ballast is the removal of transformer to reduce both the size and weight. At the same time maximising the efficiency and reducing the cost of lighting a bulb. [13][14]

2.2 Electronic Ballast

Electrical ballast is a device intended to limit the amount of current in an electric circuit. A familiar and widely used example is the inductive ballast used in fluorescent lamps, to limit the current through the tube, which would otherwise rise to destructive levels due to the tube's negative resistance characteristic. Ballasts vary in design complexity. They can be as simple as a series resistor or inductor, capacitors, or a combination thereof or as complex as electronic ballasts used with fluorescent lamps and high-intensity discharge lamps. [1] [14]

In a fluorescent lighting system, the ballast regulates the current to the lamps and provides sufficient voltage to start the lamps. Without a ballast to limit its current, a fluorescent lamp connected directly to a high voltage power source would rapidly and uncontrollably increase its current draw. Within a second the lamp would overheat and burn out. During lamp starting, the ballast must briefly supply high voltage to establish an arc between the two lamp electrodes. Once the arc is established, the ballast quickly reduces the voltage and regulates the electric current to produce a steady light output. [16]

To achieve full rated light output and rated lamp life from a fluorescent lighting system, ballast's output characteristics must precisely match the electrical requirements of the lamps it operates. Traditionally, ballasts are designed to operate a specific number and type of lamp at a specific voltage. Ballasts are used with high intensity discharge lamps which emit strong light, imitating sunlight and facilitating plant cultivation in indoor settings. These lamps save on money because they are energy efficient and last longer than the ordinary light bulbs. Ballasts function to start and control the electricity flow through a lamp. So, there is sufficient electrical current and light is emitted without destroying the bulb. In other words, ballasts regulate the electric current flowing through HID lamps so that they work properly. Electronic ballasts are also known as solid state ballasts and they are the basic power electronic components which are used to supply discharge lamps at high frequencies (kilohertz). The use of electronic ballasts is vast in our day-to-day lighting activity due to its landslide advantages over electromagnetic ballasts. In the modern world electronic ballasts use power MOSFETs which are basically low-cost, small sized and power efficient. The advantages of using electronic ballast are:

1) Increased lamp life
2) Overall lamp and ballast efficiency
3) Reduced ballast size and weight
4) Lighting quality increased

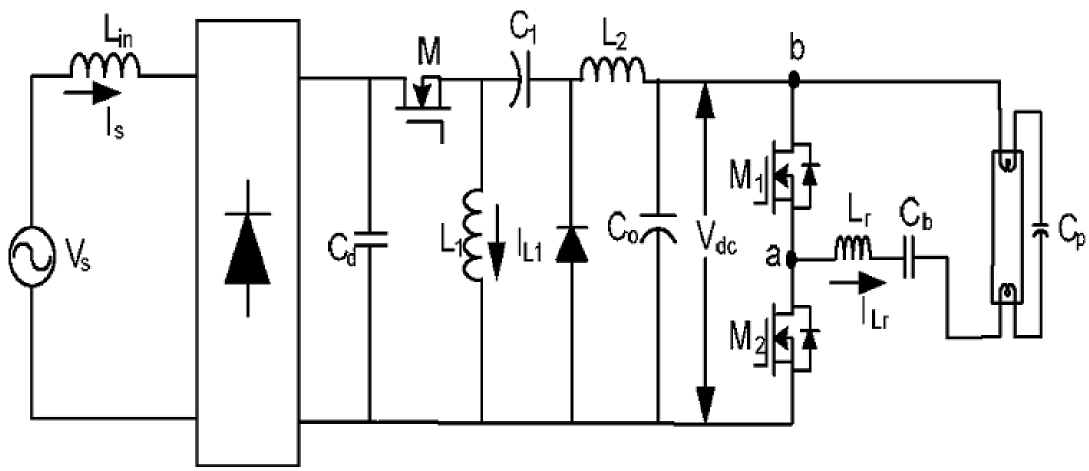

Figure 2.4: Circuit diagram of Electronic Ballast

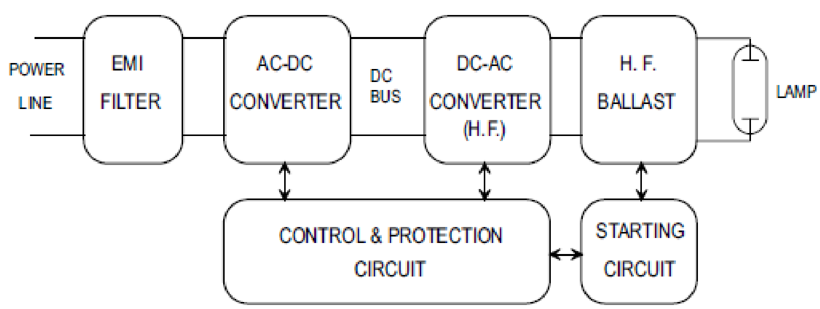

Figure 2.5: Block Diagram of Electronic Ballast

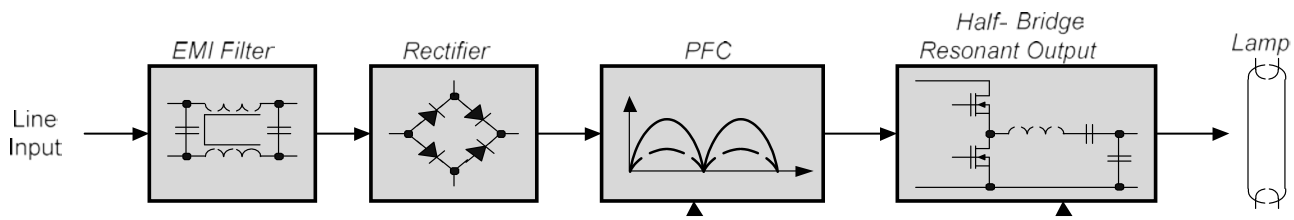

Figure 2.6: Refined Electronic ballast block diagram

2.2.1 Work Procedure of Electronic Ballast

There are several stages through which ballast works in supplying a discharge lamp. The stages are:

1) **EMI filter:** This filter is used in electronic ballasts so that the electromagnetic interference that is generated while increasing the frequency of the input current are removed. [1]
2) **AC-DC converter:** In this stage dc voltage level is generated from the ac supply of the input voltage. Basically a full-bridge rectifier is used and also a capacitor is used so that the output is as closer to a dc voltage as it can be. However the efficiency of this stage is quite low and has a bad voltage regulation. [1]
3) **DC-AC inverter:** This stage is designed to supply the discharge lamps with power at very high frequency. The inverter usually creates very high frequency waves and the

ballast is needed to limit the discharge current. Inductors and capacitors are together used in this stage for the function. [1]

4) **Starting Circuit:** This circuit is mainly used while using high-pressure discharge lamps. The main function of this circuit is to ignite the discharge lamp. In low-pressure discharge lamps the ballast is used in both igniting the lamp and also to limit the current. However in high-pressure discharge lamps the starting voltage can be very high and so a different ignition circuit is needed mainly while reigniting a already heated up lamp. Therefore the starting circuit is used to increase lamp life. [1]
5) **Control and Protection circuit:** This stage is mainly a safety stage which makes sure the overall system is not damaged in any way. The circuit contains error amplifiers, main oscillators, output over-voltage protection, over-current protection, timers which control ignition, failure protection etc. [1]

2.3 Types of Electronic Ballast

There are several different kinds of ballasts, but the 3 basic types are electronic ballasts, magnetic ballasts and digital ballasts.

Electronic and High Frequency Electronic Ballasts: Electronic ballasts regulate the electric flow inside the bulb through electronic circuitry. Sometimes referred to as control gear, the electronic ballast limits the current which flows in an electric circuit. This type of ballast is employed to balance the negative resistance to power supplies with positive resistance. As a result, the current is kept at a level that prevents the bulb from burning out. Electronic ballasts may operate in parallel or in a series mode. The series mode is preferred because the failure of a single lamp does not disrupt the working of all other lamps. The high frequency electronic ballast is another type that makes use of electric circuitry. It uses frequencies that are above 20,000Hz.

Digital Ballasts: Digital ballasts operate at higher frequencies and produce larger amount of light while using less energy. The digital component regulates temperature levels so that the bulb lasts longer. With digital ballasts, the flow is low at the initial point and increases when temperature goes up inside the bulb. It is important to note that the reliability of digital ballasts may vary depending on the manufacturer. Effective digital ballasts shut down automatically if a damaged or defective bulb is detected or in case of a short circuit. In this manner, safety hazards are avoided. [2] [17]

2.2.2 Designing Electronic Ballast

We need to consider a number of factors while making a blue print of the ballast. There are basically five factors that we need to consider:

1) **Operating Frequency:** Ballasts are operated at a particular frequency range and this is due to a number of factors. The frequency at which it is operated should be high as reactive components are used such as inductors and capacitors which a tiny in size and at high frequencies they give the best possible output. The frequency used should be higher than 20 kHz as noise interference should be avoided. The frequency used should also be lower than 100 kHz as very high frequencies can result in switching losses. The ranges of 30 to 40 kHz have to be avoided as well as they are often used in Infrared remote controls and can interfere with the operation. Overall the ballast is used in the frequency range of 50 to 60 kHz for the output to be optimum and to avoid very high losses. [1][18]
2) **Discharge Lamp Current Wave-Shape:** This factor has to be taken into consideration to prolong lamp life. In order to make sure the lamp has maximum life the input current should be highly sinusoidal, that is both the electrodes of the lamp should be used simultaneously. If the input current is not sinusoidal it might lead to early lamp aging and so would therefore not be cost effective. The Crest Factor (CF) of the lamp which is a ratio of the peak current value to the rms value of the current of the lamp. The higher the Crest Factor the lower is the lamp life and therefore it should be contained. The CF value should therefore be lower than 1.7 to make sure the lamp does not get damaged early. [1][18]
3) **Starting Process of the Lamp:** This is another important factor for better lamp life. The main dilemma is that a lamp will get less damaged if it is started properly. The procedure

of starting a lamp is perfect if only the following steps are implemented effectively. The steps are:

a) When the lamp is started the electrodes have to be heated and no high voltage should be applied unless an optimum temperature is reached.
b) Only when the electrodes are heated to the optimum temperature the starting voltage can be applied and the lamp can be ignited.
c) The starting voltage should be as low as the minimum value needed to ignite the lamp as higher voltages can shorten the lamp life. [1]

4) **Dimming:** This is an important factor in controlling the lamp's light output. Switching frequency is used in this process to control the ballast impedances and therefore to alter the discharge current. That is by using high frequency the inductor reactance can be increased and by that the impedance is also increased and so the lamp current is decreased. Dimming has to be performed effectively by making sure that the lamp power does not change suddenly and also if the power is lost then the lamp should be restarted form the same light intensity level and slowly brought down to the needed level. [1]
5) **Acoustic Resonance:** When high intensity discharge lamps are supplied at very high frequencies they start showing unusual characteristics. The bulb starts flickering due to changes in the power as the core becomes unstable. This problem can be avoided by choosing frequencies that are above 100 kHz or below 1 kHz. [1]

2.2.3 Factors Affecting Ballast Performance

There are some factors that should be taken into consideration while using electronic ballasts.

1) **Ballast Factor (BF):** It is the ration of light output by specific ballast to the light output by reference ballast. Electronic ballast has a BF of range between 0.73 to 1.50. A fluorescent lamp's light output usually depends on current which flows through the lamp as discussed earlier. A lamp's rated output lighting is given by operating the lamp at the line frequency that is 50-60 Hz. If a lamp is operated at a frequency in the kilo hertz range low amount of current is needed for the lamp to give the same lighting ratings as they operated more efficiently. Ballasts with very high Bf value are more likely to

damage the lamp and can make the lumen depreciate faster due to high lamp current. Ballasts with very low BF value can also be bad for lamp life due to low lamp current.

2) **Ballast Efficacy Factor (BEF):** It is the ratio of ballast factor to input power. It is the comparison of efficacy of the fluorescent lamp to ballast combination.

2.2.4 Problems Related to Electronic Ballast

Electronic ballasts have miscellaneous reliability value. Studies show that ballast either fails within the first six months of usage or it goes on working till ten to twelve years. The desired ballast types are not always available. This might be a concern for some fluorescent lamp wattages and other newer model of these lamps like CFL. There is a linear relationship between the wattage and the light output that is low wattage electronic ballasts have low light output.

Harmonics in the result of non-sinusoidal wave produced form devices with reactive loads. Ballasts for fluorescent lamp produce high Total Harmonic Distortion and therefore alter the sinusoidal form of the input wave drawing more power form the system than needed to drive the circuit. The effects of harmonics are:

a) Overloading of transformers
b) Overloading of neutral wire in three phase systems
c) Current or Voltage spikes which can damage any circuit
d) Distortion of the electric design in a building

2.4 Comparison of two types of ballasts (Magnetic and Electronic)

	Magnetic Ballast	Electronic Ballast
Number of lamps operated	1-4	1-4
Starting mode*	PH, IS, RS	IS, RS, PS
Weight (ibs)	3.5	0.4-5.0
Lamp operating frequency	60 Hz	20,000-60,000 Hz
System efficiency	Lowest	Highest
Ballast factor	0.63-0.99	0.73-1.30
Ballast efficiency factor	0.90-1.40	1.15-1.56
Total harmonic distortion(%)	Most<20, some>20	Some<5, most 5-2-,some>20
Power factor	Most>0.9	>0.9
Lamp flicker index	0.04-0.07	<0.01
Operating electrode voltage, rapid-start	2.5-4.4	2.5-4.4
Rated life	10-15	10-20
Sound rating	A-D	A-B
Dimming available	yes	Yes
Lamp current crest factor	< 1.7	<1.7

Table 2.1: Comparison between Magnetic and Electronic Ballast

NA=not applicable

1Ib=0.45 kg

*IS=instant start; PH=preheat; PS= programmed start; RS= rapid-star

CHAPTER THREE

DESIGN OF INTERNAL BALLAST CIRCUIT AND POWER FACTOR CORRECTION

The focus area of this thesis is the internal circuitry of ballast. As discussed beforehand now-a-days the usage of electronic ballast is growing manifold and replacing the high power consuming and heavy weighted electromagnetic ballast. The electronic ballasts are smaller in size and can be integrated within a lamp without increasing its size of weight significantly. Thus the overall cost of driving and supplying the lamp decreases due to usage of electronic ballast circuitry. CFL lamps are used mostly these days giving the rise in popularity of the usage and manufacture of electronic ballasts. The CFL lamps mostly used due to the low consumption of power and also the reduction in size but at the same time getting enough luminous intensity compared to any fluorescent lamp. As discussed before the CFL bulb is ignited through a complicated circuitry known as electronic ballast and its circuit consists of multiple components using MOSFET switches and diodes and capacitors.

The internal circuit of ballast consists of two main blocks which are a diode-bridge rectifier to convert the input AC voltage to DC and then a MOSFET switch to convert the DC voltage to AC again. The entire process is done to increase the overall frequency of the supply as the CFL lamps are usually driven at high frequencies. A capacitor is connected with the output terminal of the rectifier to obtain as much DC like voltage as can be obtained. The high frequency AC is then supplied to the ballast which in turn acts as a starter circuit of the lamp which is then driven by it and thus the lamp is ignited.

However the main problem is the generation of impulses of current in the form of spikes which distorts the sinusoidal input voltage shapes which come directly from the line. This is called Total Harmonic Distortion and is quite dangerous for electronic equipments and at the same time gives rise to reactive power loss due to the presence of diodes and switches present in the ballast circuitry which are not linear as a resistor. The power lost is in the form of reactive power and is an excess loss due to the spikes in current wave-shape. For example if we consider a CFL lamp with a power rating of 25W we can see that the apparent power used is far greater because of these non-linear components present in the circuit. The excess power drawn is unusable and yet we would have to pay for it. Thus the efficiency of the lamp along with the circuit is reduced due to the emergence of distortion in the current. The main concern of this thesis was to design a complete ballast circuitry and therefore reduce the THD by reducing the distortion in current and thereby increasing the efficiency of the overall circuit and also to maintain the linearity as far as possible of the sinusoidal voltage wave-shape. Part by part circuits are designed and implemented giving rise to the overall block circuit. Architecture has also been provided for the better understanding of the circuit that was developed in this thesis.

3.1 Total Harmonic Distortion

Total Harmonic Distortion or THD is a specification that compares the output signal with the input signal and measures the level differences in harmonic frequencies between the two. The difference is called total harmonic distortion.

3.1.1 Measuring power line distortion

The degree of the voltage distortion varies with the impedance of electrical power distribution system and the number and type of non-linear loads connected with this system. For comparing these two distortion levels, it is necessary to quantitatively describe the distortion. Harmonic analysis is used to provide this description. The level of voltage distortion that is acceptable depends on the sensitivity of the equipment. In harmonic analysis, any repetitive wave form can be described mathematically as a series of pure sine waves. These sine waves consist of a fundamental frequency and multiply of that frequency, called harmonics. There are two ways to express the results of this mathematical analysis. The most detailed method describes the amplitude of each individual harmonic component, either in absolute units (such as volts) or as a percentage of the fundamental component. With this, it is possible to determine the source of harmonic distortion. Detailed analysis also helps in designing specific filters to solve harmonic distortion problems. For a less detailed view, total harmonic distortion (THD) is often used. As a percentage, this single number is calculated by adding the square of each relative harmonic value and taking the square root. [1][19] [20]

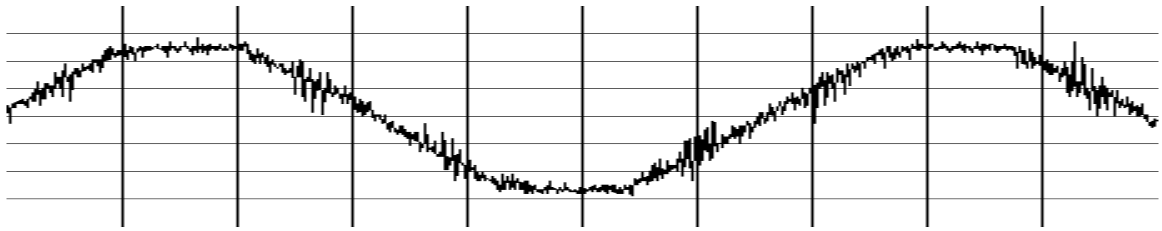

Figure 3.1: Typical phase to phase voltage distortion

3.2 Resonant and Non-Resonate Ballast

3.2.1 Non-resonant Ballast

The purpose is to supply alternative current which are basically obtained by removing the output diode of dc-to-dc converter. Current mode control is normally employed to limit the discharge lamp current. The lamp is supplied with a square current waveform, which can exhibit a dc level in some cases. A small capacitor is used to initially ignite the lamp, but its effect at steady-state operation can be neglected. A figure is given below which can supply symmetric alternating current through the lamp but present several drawbacks, such as high voltage spikes across the switch, which make necessary the use of high-voltage transistors, and high switching losses due to hard switching, which gives low efficiency, especially for high powers. In addition, because the ideal situation is the lamp being supplied with a sine wave, these circuits produce early aging of the lamp. In conclusion, typical applications of these topologies are portable and emergency equipment, where lamp power is low and the number of ignitions during its life is not very high. [1]

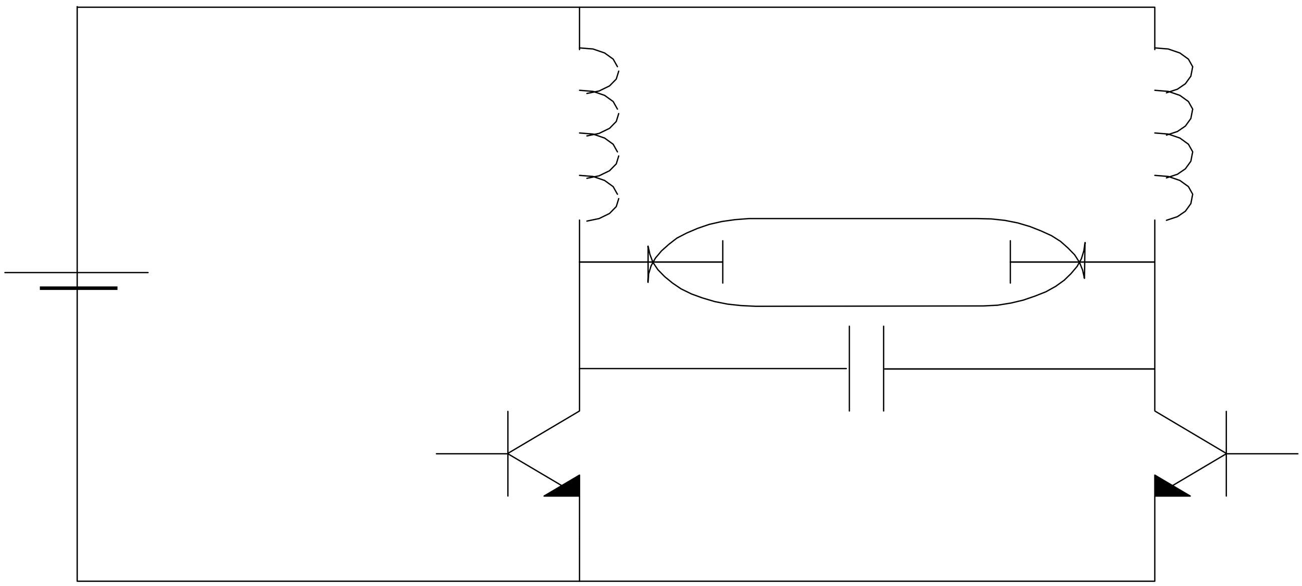

Figure 3.2: Non-resonant electronic ballast

3.2.2 Resonant Ballasts

These ballasts use a resonant tank circuit to supply the lamp. The resonant tank filters the high-order harmonics, thus obtaining a sine current waveform through the lamp. Resonant ballasts can be classified into two categories: current-fed and voltage-fed. [1]

3.2.2.1 Current-Fed Resonant Ballasts

These ballasts are supplied with a dc current source, usually obtained by means of a choke inductor in series with the input dc voltage source. The dc current is transformed into an alternating square current waveform by switching power transistors. A typical topology in this group is the current-fed full-bridge resonant inverter, which can be used for higher power ratings. Also, this circuit allows control of the output power at constant frequency by switching the devices of the same leg simultaneously, generating a quasi-square current wave through the resonant tank. [1]

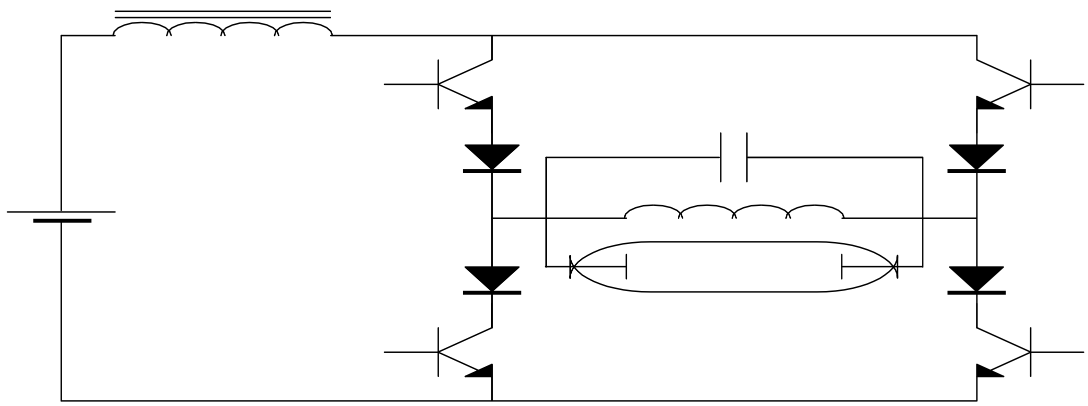

Figure 3.3: Current-fed Full-bridge

3.2.2.2 Voltage-Fed Resonant Ballasts

This type of ballast is one of those used most by electronic ballast manufacturers at the present time, especially for applications supplied from ac mains. The circuit is fed from a dc voltage source, normally obtained by line-voltage rectifying. A square-wave voltage waveform is then obtained by switching the transistors with a 50% duty cycle, and used to feed a series resonant circuit. This resonant tank filters the high-order harmonics and supplies the lamp with a sine current waveform. One advantage of the voltage-fed series resonant circuit is that starting voltage can be easily obtained without using extra ignition capacitors by operating close to the resonant tank frequency. The full-bridge topology shown in the following figure is normally used. Transistors of each half-bridge are operated with a 50% duty cycle and their switching signals are phase shifted by 180_. Thus, when switches Q1 and Q2 are activated, direct voltage Vin is applied to the resonant tank, and when switches Q3 and Q4 are activated the reverse voltage, Vin is obtained across the resonant circuit. One of the advantages of this circuit is that the switching signals of the two branches can be phase shifted by angles between 0 and 180_, thus controlling the rms voltage applied to the resonant tank in a range from 0 to Vin. This provides an additional parameter to control the output power at constant frequency, which is useful in implementing dimming ballasts. [1]

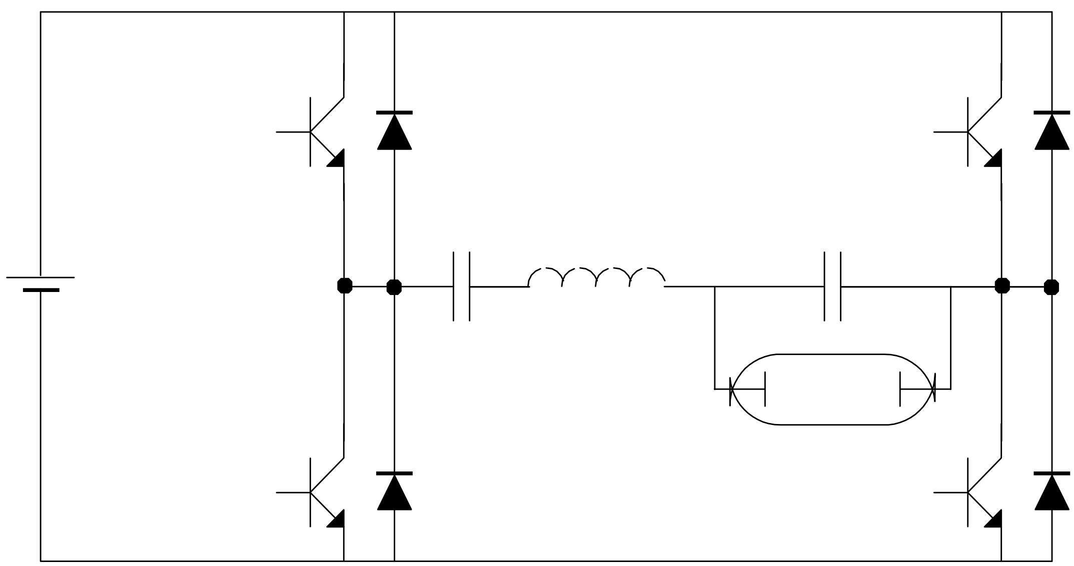

Figure 3.4: Full-bridge Voltage-fed

3.3 Ballast Supply Circuit Design used in the Thesis

For this thesis we are using a non-resonant ballast design due to the fact that we are dealing with CFL lamps which consume as less as 25W or 40W. We have designed the ballast circuit in parts and taken values of each part and made comparisons where necessary. The circuit consists of two parts which are the rectifier and then the inverter. The sole purpose is to convert the input sinusoidal AC voltage to DC voltage and then finally converting the DC voltage to AC voltage while increasing the frequency significantly as the main purpose of ballast is to supply the CFL at high frequencies. A full design has also been given at the end along with the improvements we have made to fulfill our purpose of creating and improving a theoretical model of electronic ballast for CFL.

3.3.1 Rectifier

The rectifier circuit used is a full-bridge diode rectifier along with capacitance connected to the output terminals. The main objective of this circuit is to ensure that the output voltage is as close to that of the DC level. Four diodes are placed as shown in the diagram.

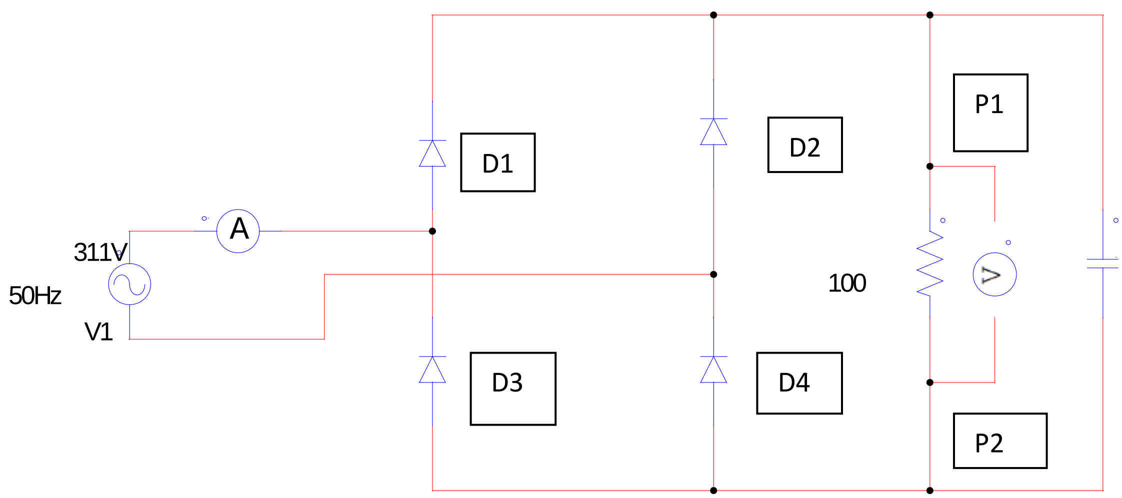

Figure 3.5: A Full-bridge Rectifier with Capacitor

An ammeter is placed with the input voltage to measure the distortion in current due to placement of diodes which direct the current in one single direction. The input voltage is 311V peak which has an rms value of 220V and the frequency used is 50Hz which is the line frequency of this country. The diodes are numbered from D1 to D4 and are placed according to the diagram. When the voltage cycle of the input source is positive diodes D1 and D4 are active and diodes D2 and D3 are open circuited and the current travels in the direction from P1 to P2 for the half cycle. The voltage of the resistor therefore shows a positive peak. In the negative half cycle of the input source diodes D2 and D3 are active and diodes D1 and D4 are open circuited and so the current travels in the direction from P1 to P2 the same as before. The voltage again shows a positive peak. The capacitor is placed so that once it is charged to the full voltage it takes time to discharge and thus due to its use the voltage never falls to zero. The wave-shave obtained for the circuit is as follows:

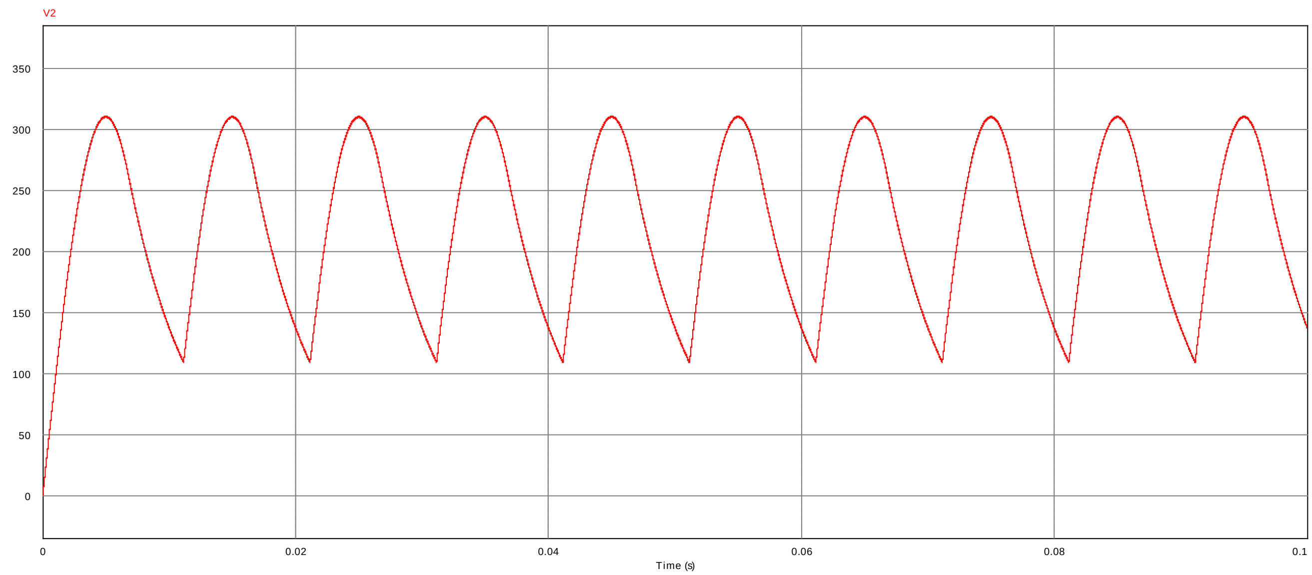

Figure 3.6: Wave-Shape with capacitance 50uF

The wave-shape shows that the input voltage which was an AC- sinusoidal supply is altered to a much resembling DC voltage. The capacitor used for the wave-shape is 50uF.

However this rectifier which converts the AC voltage to DC voltage has one big drawback. The usage of diodes itself distorts the input current wave-shape giving rise to THD which is quite harmful for other electronic equipments and also draws in over power. The capacitor used with a very small value of 50uF also gives rise to distortion and thus the power factor of the circuit lessens and more power is drawn from the source which should not have been drawn. The current wave-shape is as follows.

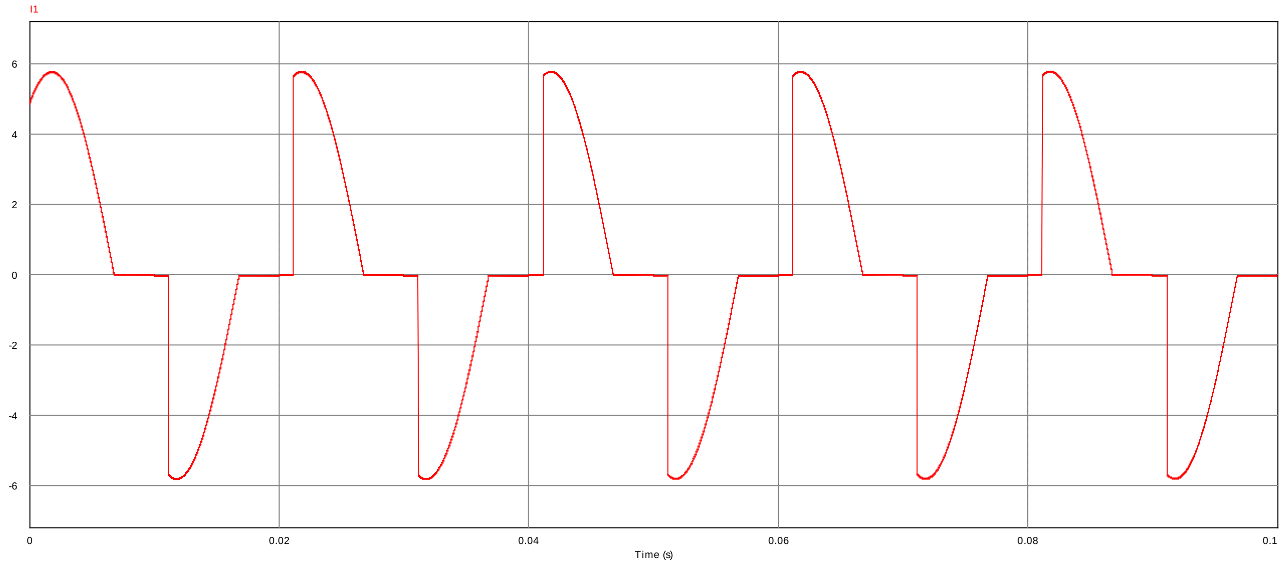

Figure 3.7: Distorted Current Wave Shape with C=50uF

The THD value obtained for this wave-shape is approximately 46.32% which is reason for the parasitic power loss.

The simulation was redone with increasing value of the capacitance to see the effect of it on the current wave-shape and the THD value. This time we used a capacitance of 500uF to see the effects. The voltage wave-shape obtained was as follows.

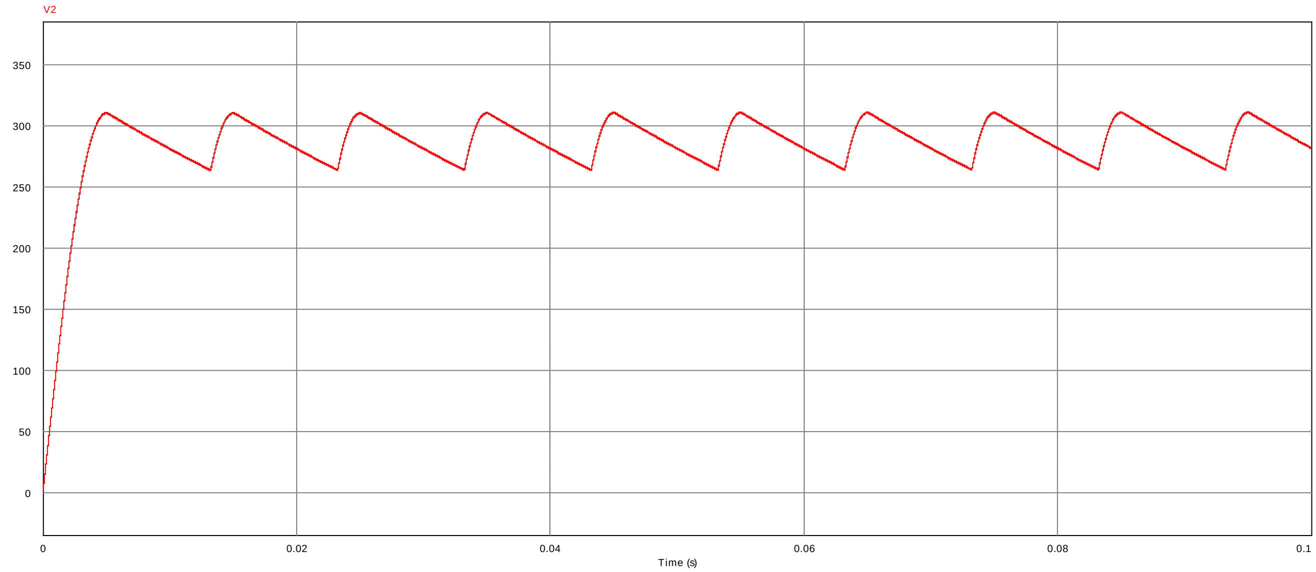

Figure 3.8: Wave Shape with Capacitance 500uF

As seen in this figure the output voltage wave-shape is improved to something close to that of the DC level. However if we take a close look on the input current wave-shape we will have a very different idea of how much distorted the current wave-shape can be. The following wave-shape is that of the current.

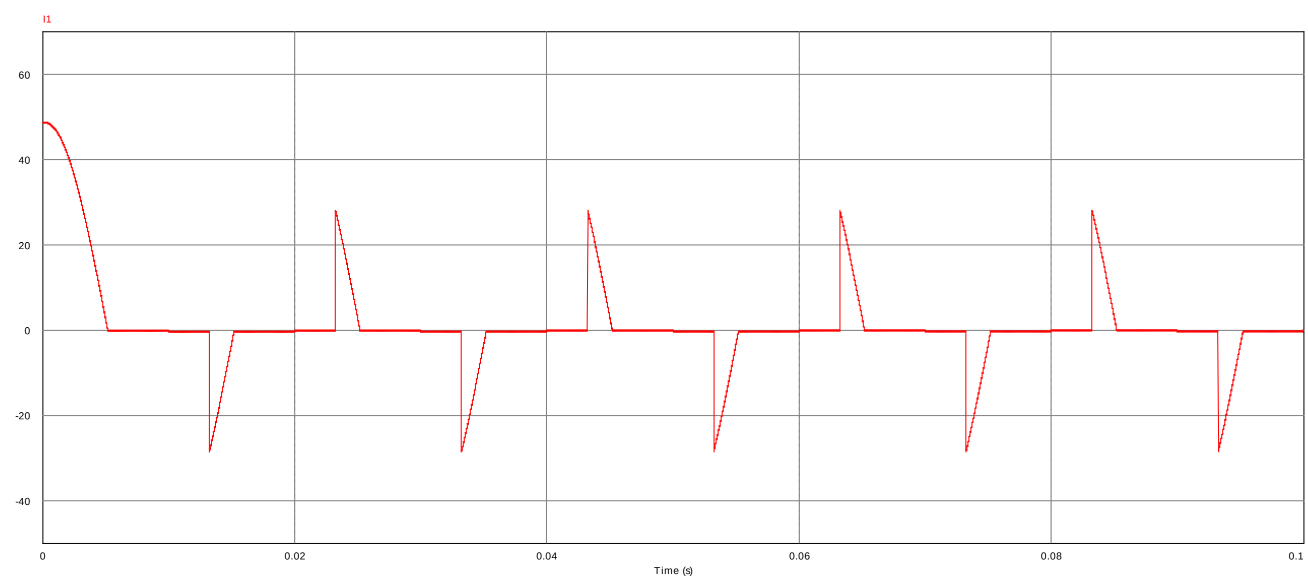

Figure 3.9: Distorted Current Wave Shape with C=500uF

Here the current is even more distorted than before as the spikes are sharper. The THD value of the current is 111.38% which is more than twice of that of the THD value for the capacitance of 50uF. The power wastage is significant due to the consumption of reactive power which is harmful for electronic equipments.

The simulation was again repeated for double the capacitance value which in 1mF or 1000uF. The voltage wave-shape obtained is as follows.

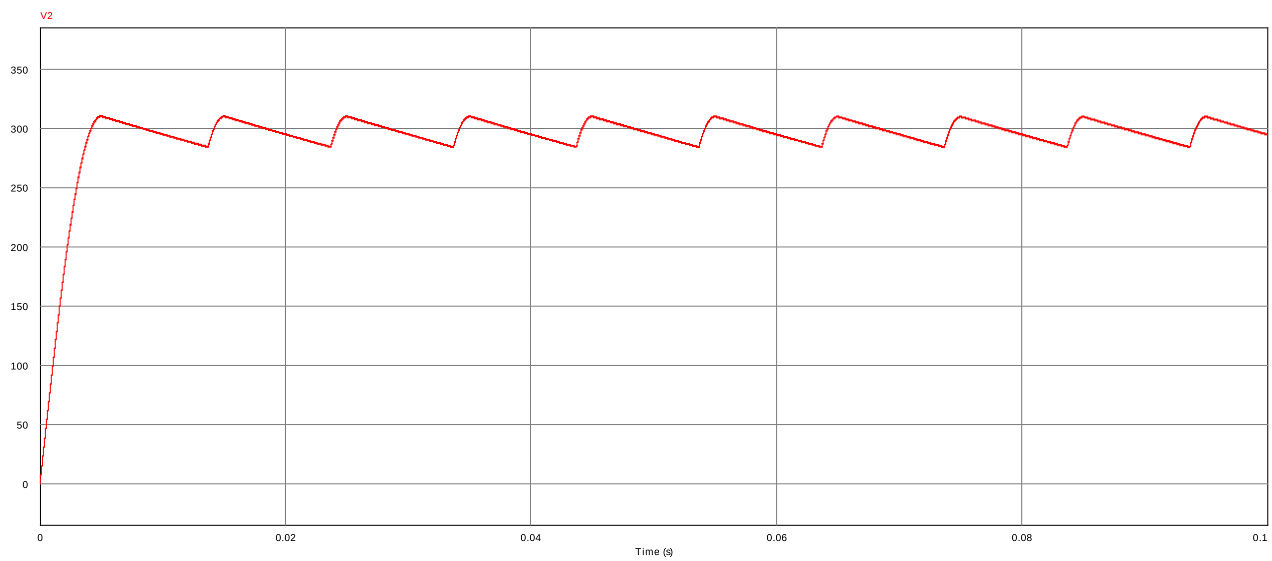

Figure 3.10: Wave-Shape with capacitance 1000uF

As seen in the figure the voltage is very much closer to the DC voltage and even better than before. However the cost of THD is evening greater comprising of a resounding 122.44% which is even higher compared to that of the THD produced when a capacitance of 500uF was used. The current wave-shape is as follows.

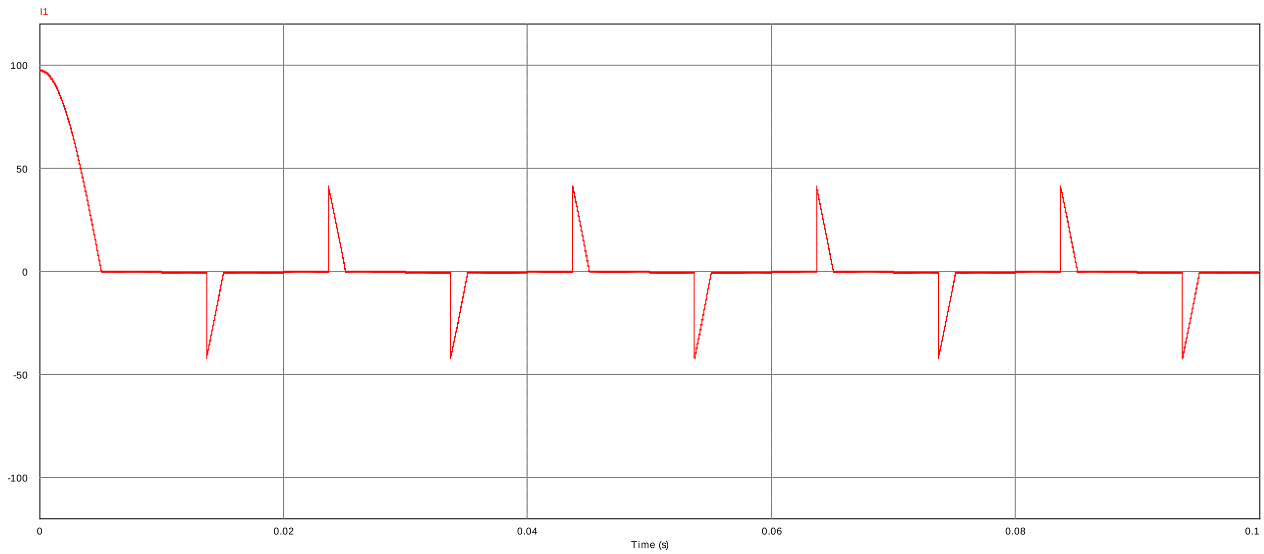

Figure 3.11: Distorted Current Wave Shape with C=1000uF

3.3.2 Inverter

The inverter circuit used is a MOSFET inverter with diodes connected in parallel to each of the MOSFETs. The objective of this circuit is to convert the input DC voltage to AC voltage which is then supplied to the resistive load. The following figure displays a simulation done by us of an inverter.

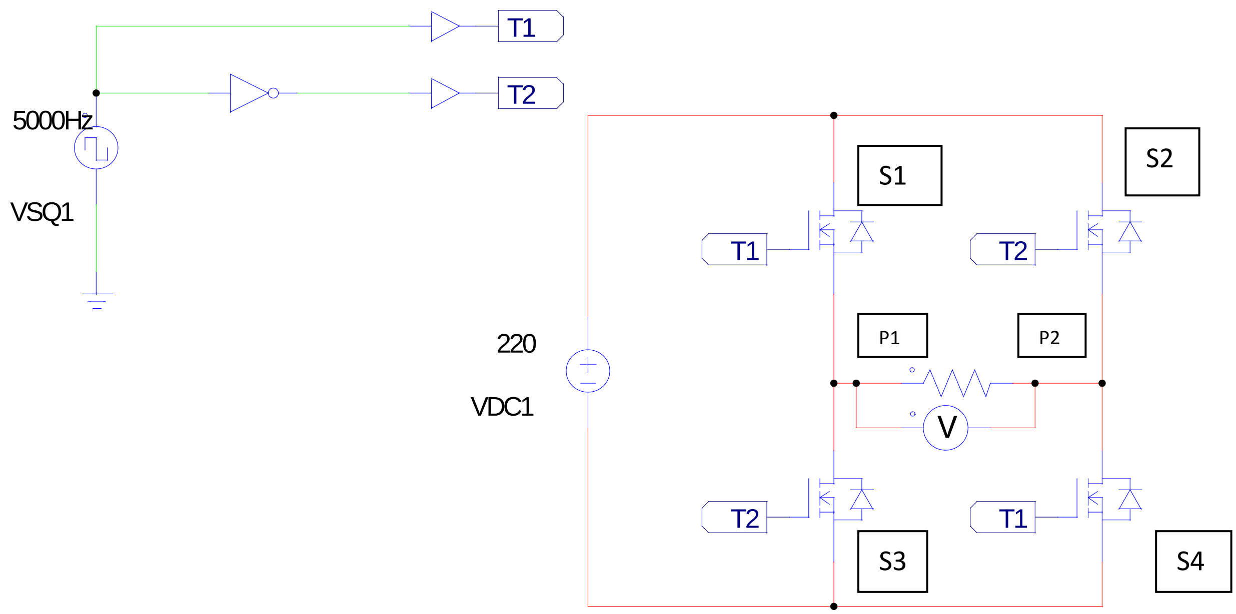

Figure 3.12: Inverter Design Using MOSFET Switches

We have used a frequency of 5 kHz to drive the MOSFETs (IRF540). These MOSFETs in parallel with the diodes serve as switches. We have only used square-wave to drive the switches and configured it in a way that when S1 and S4 are active S2 and S3 is open circuit. The square-wave signal given to the switches is supplied from the source VSQ1 and the wave is inverter at T2. T1 is supplied to S1 and S4 at a given instance and then in the next instance they are switched off as the voltage of T1 varies from binary 0 to 1 and is a on-off switch. The same thing happens for T2 and as a result of this S1 and S4 are simultaneous with S2 and S3. Now if we consider switches S1 and S4 are on then the current flows from P1 to P2 giving a positive peak of square wave. Then if we consider switches S2 and S3 and on then the current flows from P2 to P1 giving a negative peak square wave. The wave-shapes of this inverter are as follows.

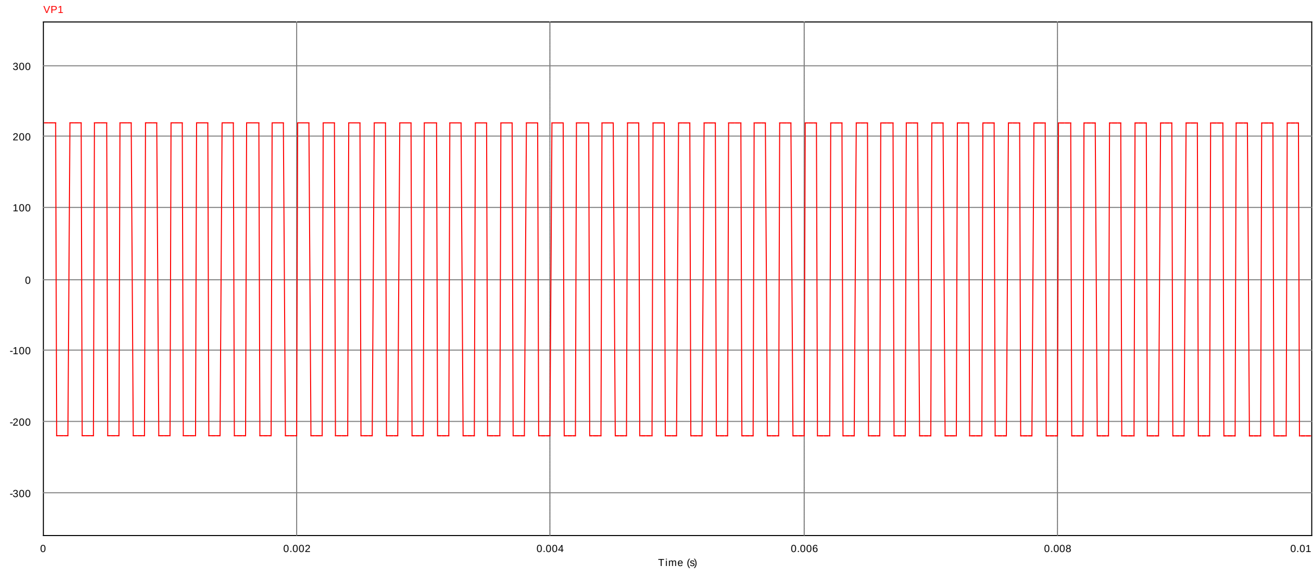

Figure 3.13: Voltage Wave Shape of an Inverter (Square Wave Format)

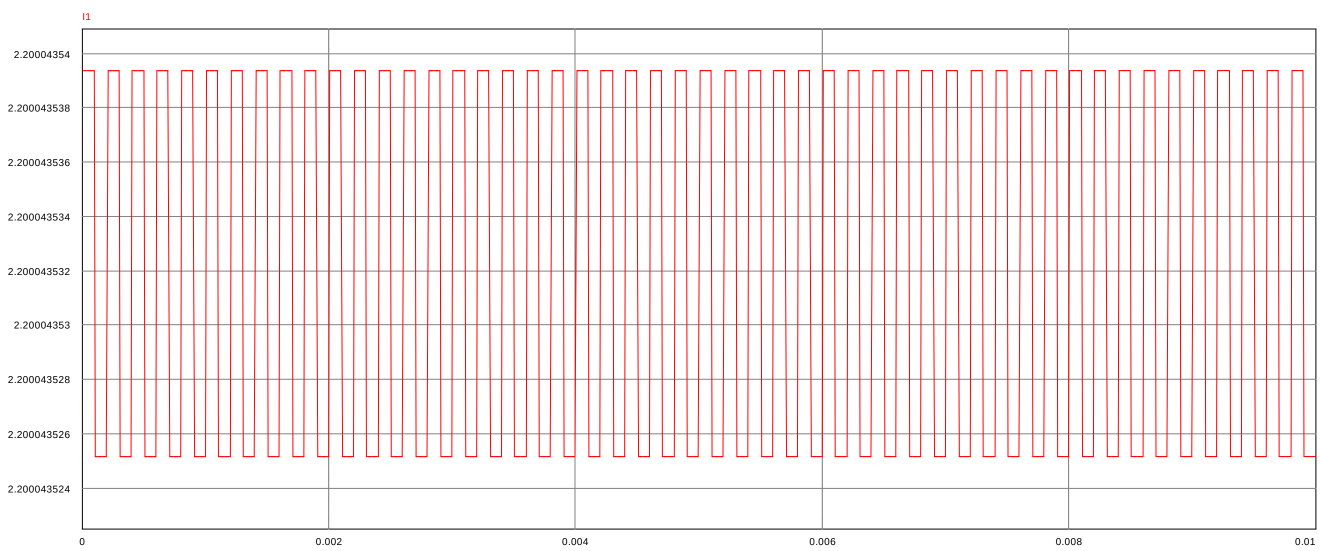

Figure 3.14: Current Wave Shape of an Inverter (Square Wave Format)

3.3.3 Inverter and Rectifier Combined

From the earlier designs we were able to combine both into a single design consisting of both a rectifier and an inverter. The main objective was to convert from AC voltage to DC and then to AC again while increasing frequency of the voltage significantly. This was effectively done in this following circuit.

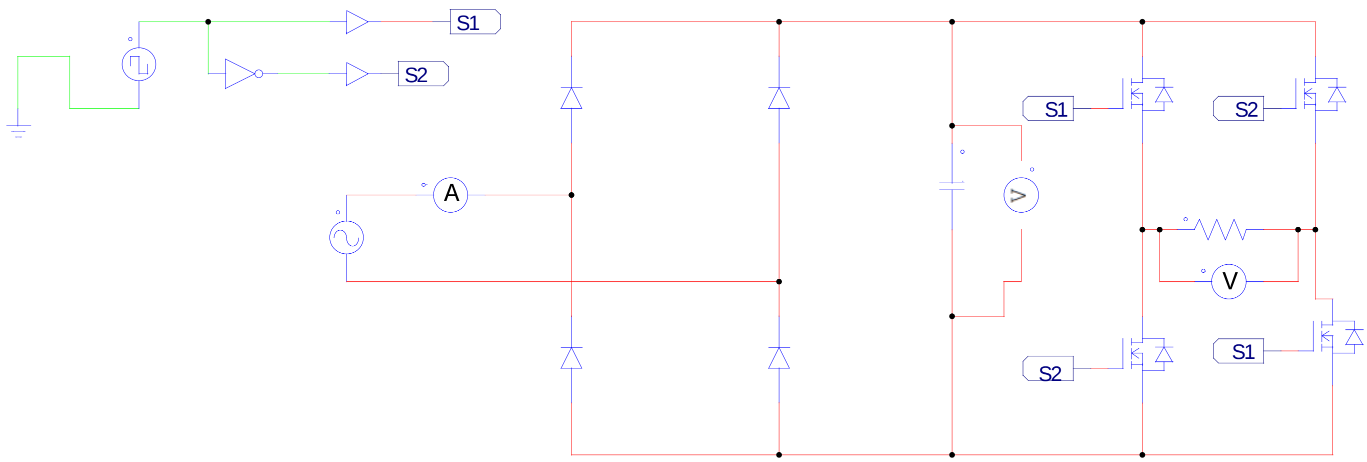

Figure 3.15: Complete Rectifier and Inverter circuit

The circuit is as shown. The first part before the capacitor is the rectifier and the output of the rectifier is connected to the inverter. The inverter is the same design as discussed before and so is the rectifier. The simulation is done the same way as before with a switching frequency of 5 kHz of attain a overall high frequency with the same voltage level as the input voltage. Readings were taken the same way as before by changing capacitance values.

The first wave-shapes of voltage and current are as follows with a capacitance value of 50uF.

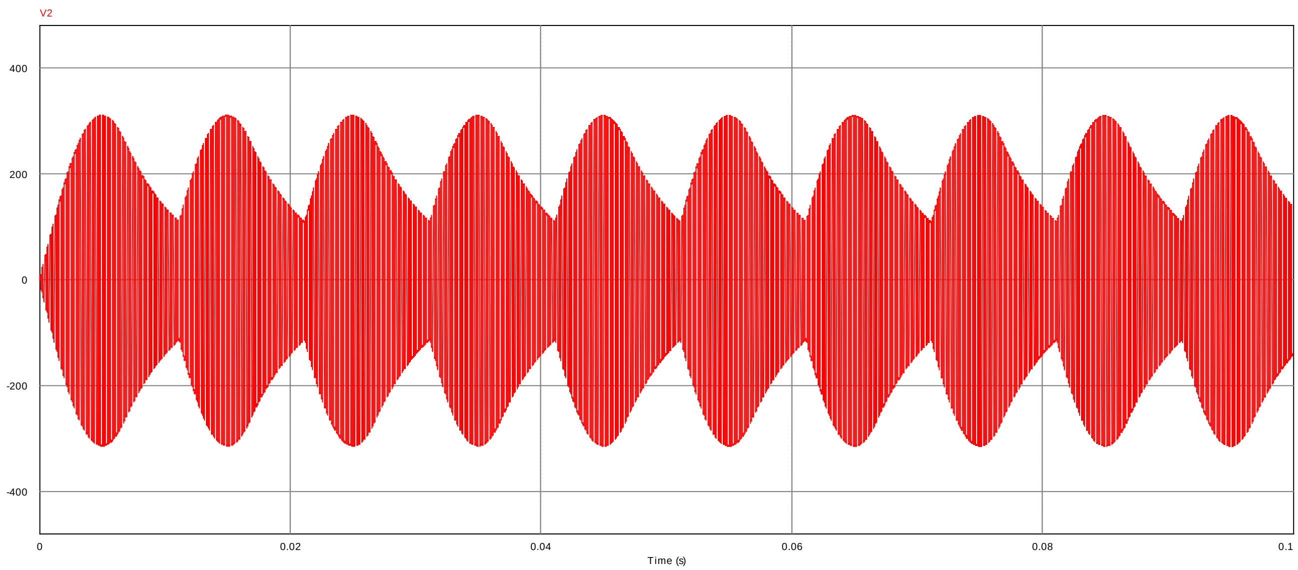

Figure 3.16: Voltage Wave-Shape across Resistor with Capacitance= 50uF (V_out)

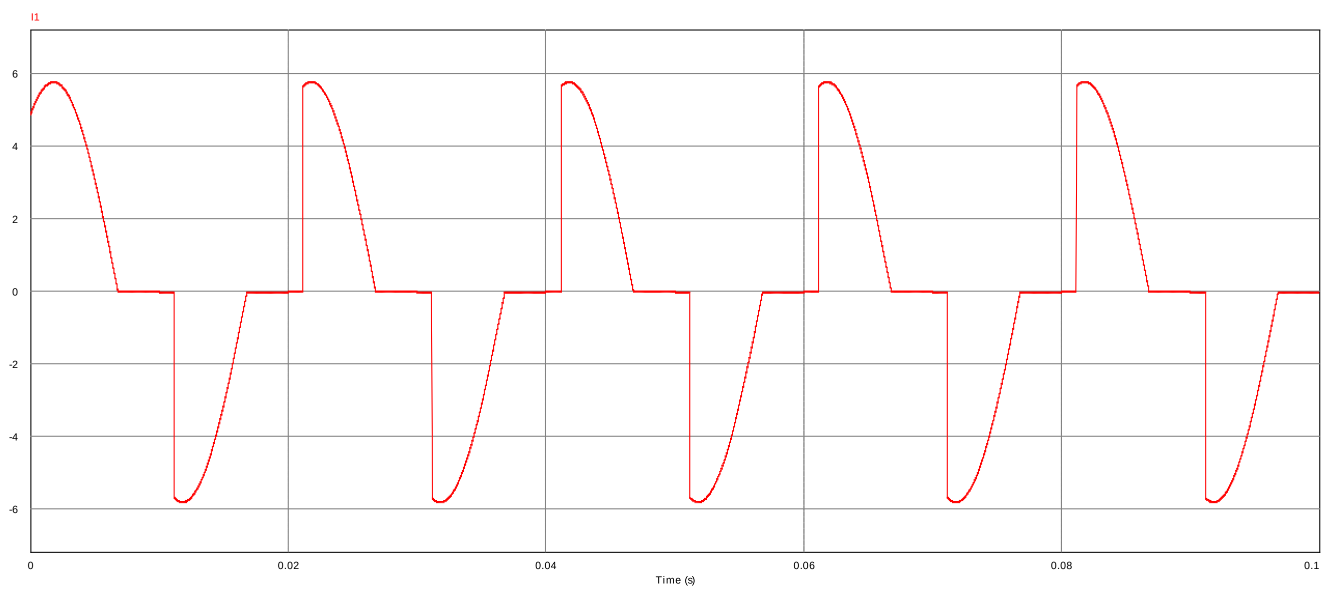

Figure 3.17: Wave-Shape of Input Current with Capacitance= 50uF (I_in)

The THD calculated was 46.31% which is almost similar to that of the rectifier THD and it can be observed that the inverter causes very small amount of distortion.

The second wave-shape was taken at a capacitance of 500uF. The following wave-shapes are the shapes of output voltage and input current.

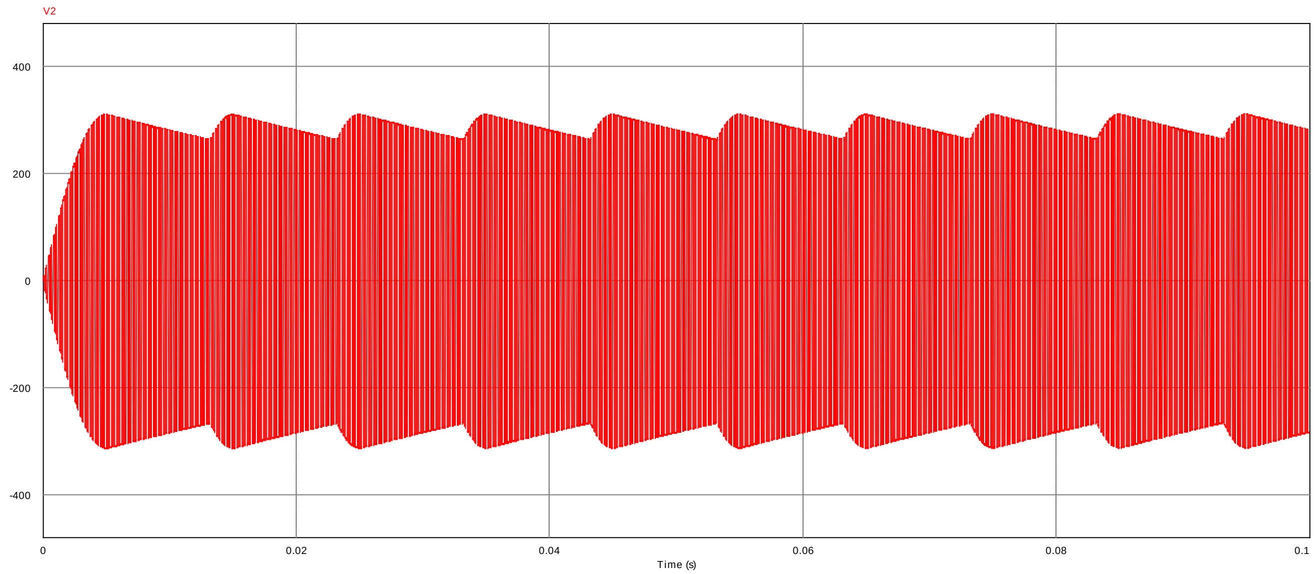

Figure 3.18: Voltage Wave-Shape across Resistor with Capacitance= 500uF (V_out)

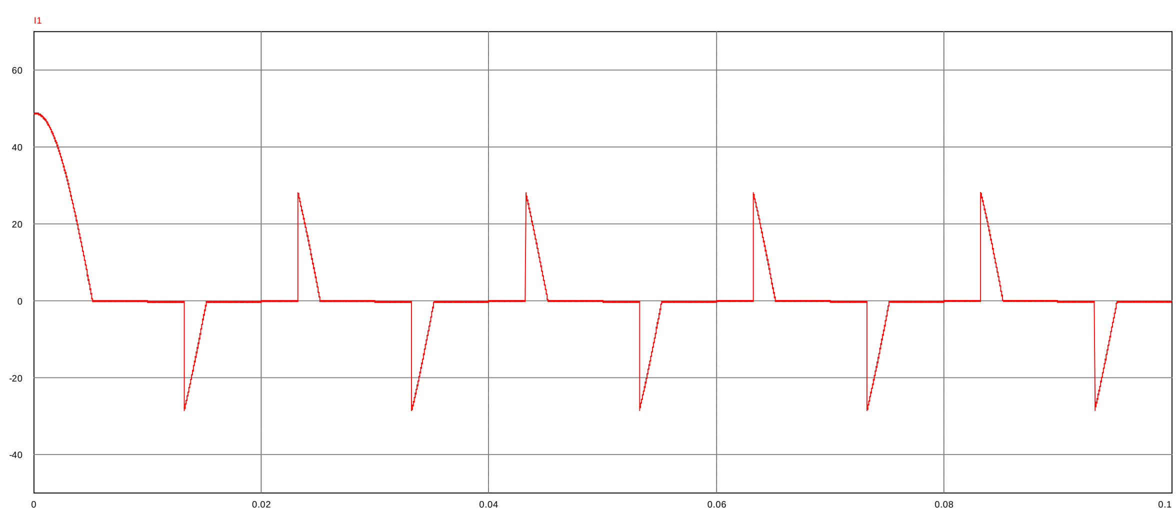

Figure 3.19: Wave-Shape of Input Current with Capacitance= 500uF (I_in)

The THD calculated was 111.38% which is almost similar to that of the rectifier THD and again it can be seen that the inverter causes almost no distortion.

The final wave-shape was taken at a capacitance of 1mF or 1000uF. The following wave-shapes are the shapes of output voltage and input current.

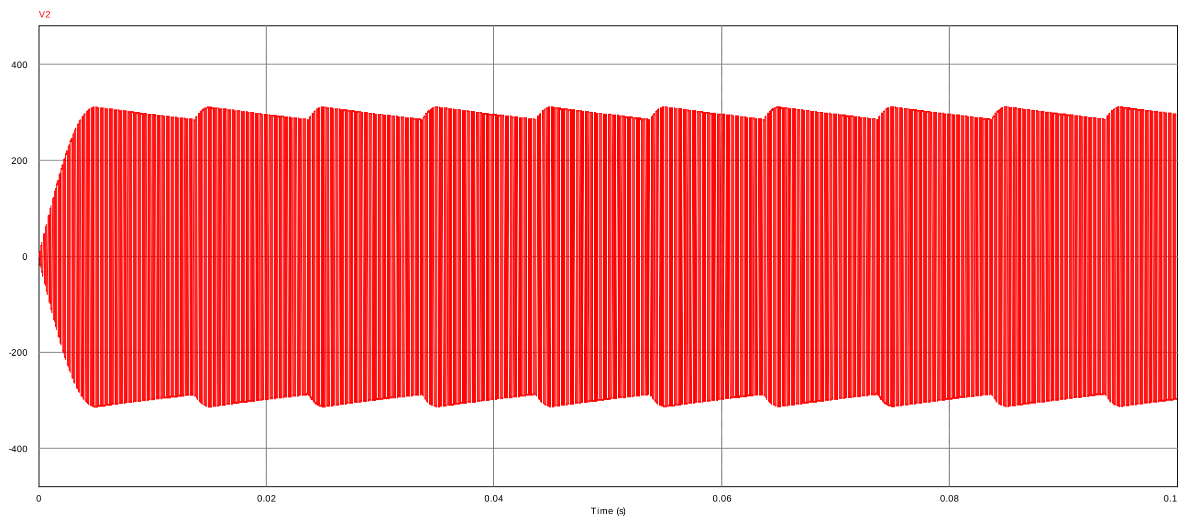

Figure 3.20: Voltage Wave-Shape across Resistor with Capacitance= 1000uF (V_out)

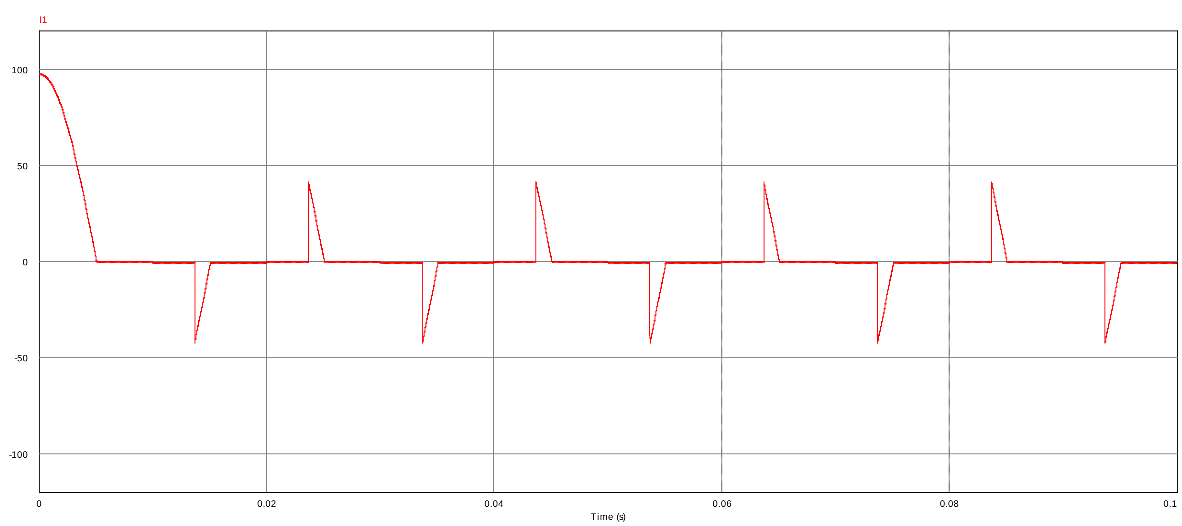

Figure 3.21: Wave-Shape of Input Current with Capacitance= 1000uF (I_in)

The THD calculated was 122.44% which is almost similar to that of the rectifier THD and so it can be concluded that the inverter causes almost no distortion and the main source of distortion is the rectifier with the capacitor connected in parallel to the output terminal. The increase in value of the capacitor is the ultimate reason for the increase in THD. So in short the closer the wave-shape of the output voltage comes to DC like voltage the more is the distortion in current as THD value raises. This is the main reason for drawing reactive power and thus more power is drawn then it should be. As a result the power factor of CFL falls and the less the power-factor the more the distortion. If left unchecked this can overload electronic equipments and cause harm to sensitive circuits.

A table is provided as follows simplifying the THD for each of the two circuits.

Capacitance value used (uF)	Rectifier Circuit (THD)	Rectifier and inverter Circuit (THD)
50	46.32%	46.31%
500	111.38%	111.38%
1000	122.44%	122.44%

Table 3.1: Comparison of Rectifier and Rectifier along with Inverter in terms of THD

3.3.4 Statistics Considered

Now if we consider a CFL to have a THD of about 40% and other equipments in the household like fan regulators, air conditioner, UPS etc to have a THD of 50% the following scenario comes into account.

For our experiment we are considering a small area of Rayer Bazzar. This area consists of several buildings in a small radius. If we consider one household to have 3 bed, 1 dinning, 1 kitchen, 1 drawing and 2 bathrooms then we can consider that one apartment would have 8 CFL, one installed in each of the room. Furthermore a household usually contains 1 UPS for a computer, 2 air conditioners and at least 5 fan regulators consisting of power electronic circuitry.

Now as seen in this area most buildings have only 2 flats per floor and most of the buildings are 7 storied or lower. For the statistical purpose we have taken only a part of Rayer Bazzar that is the area around Mukti theatre. The statistics are such:

Number of Floors in Building	Number of Buildings (NB)	Light bulbs per Building (LB)	Other Power Electronic per Building (PB)	Total percentage THD (%) $[\frac{LB \times 40\% + PB \times 50\%}{LB + PB}]$
3	2	96	60	43.85
4	4	256	160	43.85
5	15	1200	750	43.85
6	4	384	240	43.85
7	6	672	420	43.85
7<	1	160	100	43.85
Total	**32**	**2768**	**1730**	**43.85**

Table 3.2: Statistics on many Power Electronics Components used in Household

As we can see here the number of CFL used in a small area is huge and the same goes for other THD generating equipments. The percentage of THD generated on an average is around 44% and is a approximate value considering we have just assumed the number of bulbs and other equipments per floor. Not all buildings have the same structure so the data might vary from building to building. We have just taken an average through our assumptions and the data we got shows the huge number of bulbs and other equipments used in an area even smaller than 1km^2. This gives us a idea of how much reactive power is being produced if we have a power factor very low for each of the equipments that generate THD. The power is paid from our pockets but has no benefit. It is rather harmful for electronic equipments through several factors like over-heating, over-loading, flickering etc. High currents can also burn out equipments and in some cases the equipment might also catch fire and harm the residence of the area.

3.4 Active Power Factor Correction Circuit

Due to the generation of a lot of THD from the rectifier circuit we have designed a Power factor correction circuit between the rectifier and the inverter so that the input current wave-shape can be improved. The circuit is designed as follows.

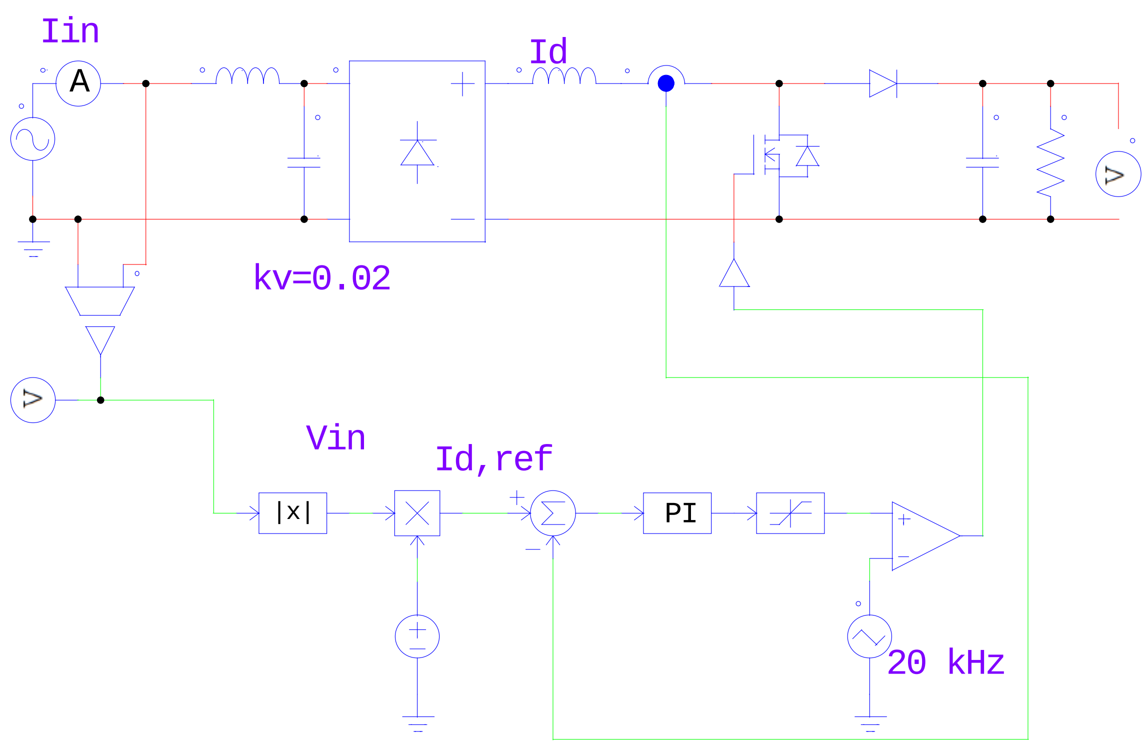

Figure 3.22: Power Factor correction Circuit

Here we have used a voltage sensor is used as shown in the diagram as well as current sensor. The input of voltage is sensed and a fraction of it used in the control circuit. The voltage is then multiplied using a reference voltage. And the feedback from the current sensor is then summed with it. A boost circuit is used in between the rectifier and inverter which acts as a DC-DC converter and enhances the input voltage. The MOSFET is driven by using a comparator with a reference high frequency voltage source and the output of the negative feedback circuit and the Id_ref. Here the Boost circuit along with the control feedback circuit acts as the Power factor correction circuit. The input current wave shape is as follows.

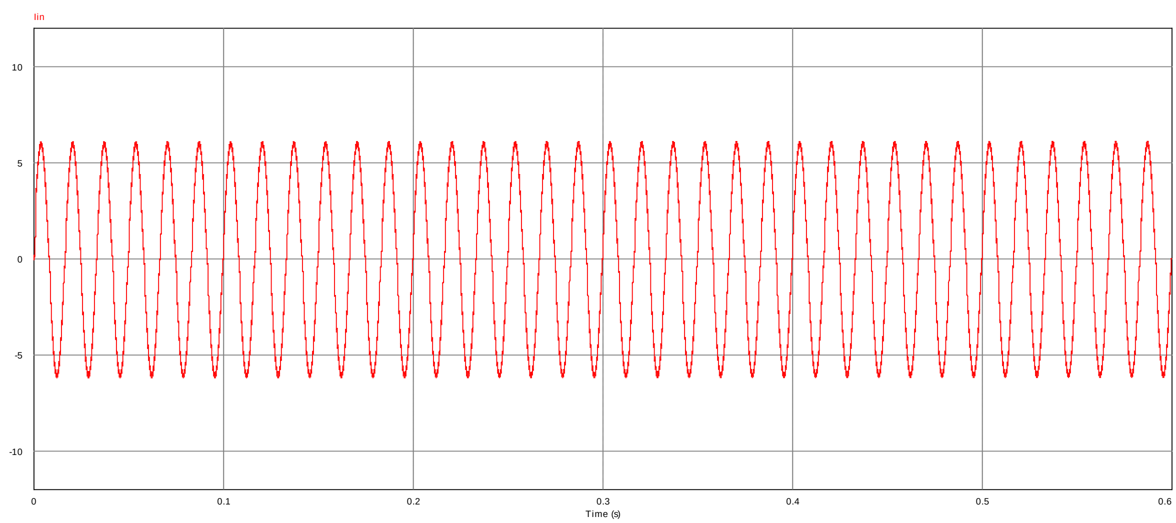

Figure 3.23: Input Current Wave-shape Improved to near Sine wave

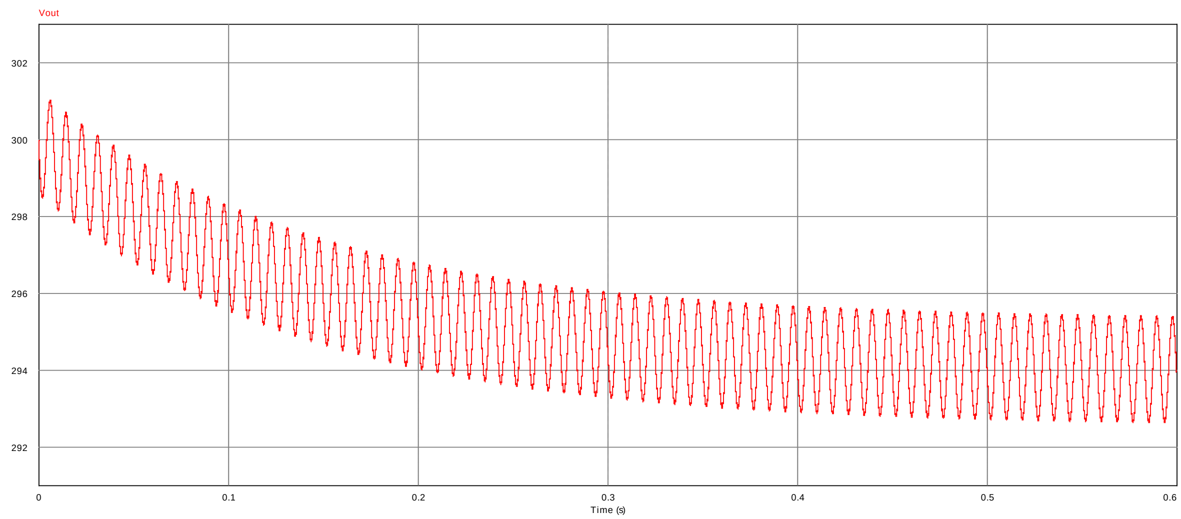

Figure 3.24: Output Voltage wave-shape of the circuit

It is seen from the wave-shape that the current wav-shape is quite sinusoidal though not completely. The Voltage level becomes stable after 0.3s and has quite high frequency. It is seen that the THD is about 40.43% even after using a capacitance of 0.002F which is quite high considering a percentage of 122.44% for only 0.001F before. Hence we can conclude Active power factor rectification circuit improves the power factor.

CHAPTER FOUR

CONCLUSION

Power Electronics is one of the leading sectors of the world and is growing rapidly as well. The reason for its growth is the discovery of micro electrical components as MOSFETs and BJTs. Now-a-days a major percentage of the household use power electronic driven circuits and so the usage of power electronics growing rapidly all over the world. From regulators to light bulbs, from UPS to air-conditioners every single component has power electronic circuits in them. Due to fact that these components are same and light weight and also do not take a lot of space and can be carried easily from one place to the other makes these components desirable for household and industrial usage. In our paper we have studied the benefits of power electronics in lighting and also found the possible problems caused by the non-linear circuits used in them.

THD is an issue that is the main reason for all kinds of problems caused by power electronic circuitry and is needed to be resolved. In this thesis we have shed light on how much damage is caused by the distortion of the input current due to diodes and capacitors. We have further discussed about three different kinds of lamps and worked mainly on the internal ballast circuit of CFL. We have also researched about two types of ballasts which are magnetic and electronic ballast. It is seen that the CFL uses electronic ballasts and the components in the ballast are power electronic components consisting to two circuits which are a rectifier followed by an inverter.

All in all a vast view of what is used in a CFL has been studied and dissected into parts and then implemented using power-simulation software to find a theoretical explanation of how the circuit works and what are the problems caused by it. In our paper we extensively studied the internal circuitry of electronic ballast and CFL and put forward a wide view of how the internal circuit works along with the obstacles it creates. The distortion in current is quite a problem in modern times as in this country the shortage of electricity is one of the main problems. Therefore the wastage of electric power should be as much lowered as possible if the whole country wants to obtain and retain power. The emersion of harmonics due to the non-linear circuits in the ballast of a lamp is more dangerous than known to the citizens of the country. The reactive power wasted if can be harvested would be beneficial to the country. Thus people must be aware of the fact that low power factor is harmful for any electrical equipments and should be avoided. The cost of a bulb with a high power factor might be high but the energy saved due to it is immense which makes up for its prize ten folds. Therefore this thesis has been successful in shedding light on this notion.

4.1 Future Works

Further research can be done by using better power factor correction circuit and also the development of cheap power factor rectification circuits. Work can also be done on other electrical components that use power electronics components such as diodes and MOSFET switches in the form of rectifiers as the main distortion is due to the rectifier itself. As we decrease the THD the power factor increases and so less reactive power is drawn from the source. We can use this active PFC circuit in fan regulators as well as other power electronic devices The main notion would be improving the power factor of each component so that the reactive power loss is compensated as far as possible.

References

[1] Muhammad H. Rashid, “Power Electronics Handbook.”

[2] Marc T. Thompson, Ph.D., “Notes 01 Introduction to Power Electronics.”

[3] Charles D. Wrege J.W. Starr. “Cincinnati's Forgotten Genius, Cincinnati Historical Society Bulletin 34 ”: 102–120. Retrieved 2010 February 16.

[4] Kharagpur, “Power Semiconductor Devices.”

Module 1, Version 2 EE IIT.

[5] https://www.nelt.co.jp/english/products/useful/01.html, last seen on 26/12/2014

[6] Keefe T.J., “The Nature of light.”

[7] MacIsaac, d., Kanner, G., & Anderson, G. (1999). “Basic Physics of the Incandescent Lamp. THE PHYSICS TEACHER” , Vol. 37,pp520-525.

[8] http://www.ecy.wa.gov/mercury/mercury_light_bulbs.html (last seen 27/12/2014)

[9] http://www.epa.gov/waste/hazard/wastetypes/universal/lamps/index.htm (last seen 27/12/2014)

[10] Jacques, Carole, “LED Lighting Market to Grow Over 12-Fold to $25 Billion in 2023, Lux Research”

[11] http://www.continental-lighting.com/led-basics/advantages-disadvantages.php

[12] Crestron Electronics, Inc. "infiNET dimmer datasheet" (PDF).” 9 March 2005. Retrieved 22 July 2013.

[13] http://ateam.lbl.gov/Design-Guide/DGHtm/electronicvs.magneticballasts.htm

[14] Ned Mohan, Tore M.Undeland, William P. Robbins, “Power Electronics.”

[15] Hughes, Thomas P. (2004). “American Genesis: A Century of Invention and Technological Enthusiasm (2nd ed.)”. Chicago: University of Chicago Press.

[16] http://www.engineersgarage.com/articles/electronic-ballast

[17] A Pacific Energy Center Factsheet, “Energy Efficient Fluorescent Ballasts.”

[18] http://www.lrc.rpi.edu/programs/nlpip/lightinganswers/adaptableballasts/ballast.asp

[19] Danfoss. “Harmonic Distortion of the AC Power Line”

http://www.danfoss.com/NR/rdonlyres/37FCE24B-29AD-4842-8112-3C4B6DD0C183/0/HarmonicDistortionoftheACPowerLine.pdf

[20] http://www.danfoss.com/NR/rdonlyres/AF4DDB73-B11C-4886-B1E0-3F76C1ACDF06/0/inst_po_garmonikam_ENG.pdf

[21] A. Vitanza, R. Scollo, A. Hayes, “Electronic fluorescent lamp Ballast.”

[22] S. A. Khan, R.Rahman, F. Shabnam and A. Azad, “Low Cost Cylindrical Lumen Testing procedure in Bangladesh Perspective.”

[23] A Pacific Energy Center Factsheet, “Energy Efficient Fluorescent Ballasts.”

[24] Azuan Bin Alias, “Modeling and Simulation of Single Phase Inverter with PWM using MATLAB/SIMULINK.”

[25] Sarah K. Rönnberg, Math H.J. Bollen, Mats Wahlberg, “Laboratory and field measurements of the power factor and the harmonic emission from energy-efficient lamps.”

[26] http://www.st.com/web/en/resource/technical/document/application_note/CD00003900.pdf

[27] National Lighting Product Information Program, “Electronic Ballast.”
Non-dimming electronic ballasts for 4-foot and 8-foot fluorescent lamps Volume 8 Number 1, May 2000.

[28] ELC, “Impact of Energy Saving Lamps on the Power Quality of the Grid.”

[29] Hollister, S. (2014, jan 1), “The incandescent light bulb isn't dead. Retrieved dec 22, 2014”

http://www.theverge.com/2014/1/1/5263826/the-incandescent-light-bulb-isnt-dead

[30] Hughes, Thomas P. (2004). “American Genesis: A Century of Invention and Technological Enthusiasm (2nd ed.)”. Chicago: University of Chicago Press.

[31] http://www.epa.gov/waste/hazard/wastetypes/universal/lamps/index.htm (last seen 27/12/2014)

[32] Newnes ,“M. A. Laughton *Electrical Engineer's Reference Book Sixteenth Edition.*”

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